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Evaluación de impactos humanos en ecosistemas terrestres antárticos

Un análisis de las presiones humanas y estrategias de gestión en las zonas libres de hielo de la Antártida Marítima

Memoria presentada por **Luis Rodríguez Pertierra** para optar al grado de Doctor en Ecología

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A mis padres, a mi tía Ester
y a Teresa, por todo

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Más que una lista detallada esta mención es una nota cronológica dedicada a todos los compañeros de distintas instituciones que estuvieron presentes de una u otra forma durante el desarrollo de la presente tesis. A continuación resumo mi gratitud a todos vosotros, por vuestro apoyo y aliento a lo largo de este viaje llamado tesis.

En primer lugar, dar las gracias de manera especial a mi tutor, Javier Benayas que me ha apoyado durante estos años contra todas las adversidades, batallando desde su despacho para que esta tesis se inicie y se complete. No puedo olvidar la deuda inmensa contraída con la gente que hizo posible de muchas maneras mi trabajo científico en la Antártida haciendo el sueño sólido como el hielo. Gracias en particular a Antonio Quesada que me llevó al hielo por primera vez en 2010 (a la Península Byers) y cuya experiencia y liderazgo en el campo rivaliza la de los primeros exploradores. Gracias a Ana Justel por trasmitirme esta pasión, que además de darme soporte científico me preparó entero para afrontar los rigores del frio. Los presentes trabajos son fruto de un equipo de investigación y los resultados obtenidos son en gran medida gracias al esfuerzo de estas personas. Algunos de ellos luego fueron propiamente compañeros de expedición (Antonio, Lars, Paco, Javier y Pablo), aquí destacar a Pablo Tejedo que aparte de un magnifico compañero de trabajo esencial para la tesis, lideró con maestría la expedición de 2011 a Isla Decepción. También dar las gracias a Paco Lara de quien tanto el aprendizaje científico como el entusiasmo tanto en el campo como en el laboratorio han sido verdaderamente inestimables para este trabajo. Estos viajes inolvidables se completaron en 2012 con la dirección de Javier a confines algo más remotos de la Península Antártica.

Pero la Antártida no parece remota en verdad. Solamente la campaña polar española involucra a cientos de participantes de todo tipo (científicos diversos, técnicos de la UTM, así como militares de la Armada, y del Ejército de Tierra, entre otros). A lo largo de tres campañas en el campo solo conoces a algunos de aquellos que ponen en marcha la maquinaria, y aun así son imposibles de enumerar; como los miembros de la Juan Carlos I, los participantes del campamento Byers, los habitantes de la base Gabriel de Castilla, o las dotaciones y pasajeros del BIO Las Palmas y el BIO Hespérides. Como ejemplos más habituales me vienen Hilo Moreno, Miguel Ángel de Pablo y Antonio Molina por los muchos momentos felices compartidos en la Antártida. Es una suerte haber conocido gente tan diversa con visiones tan extraordinarias.

Como resultado tras cada viaje a la Antártida una gran cantidad de muestras y datos son recogidos y deben ser aprovechados. Por suerte hemos sido muy bien provistos por otros muchos compañeros e instituciones. En primer lugar hemos disfrutado de las instalaciones de los departamentos de Ecología, Biología, Geología y Matemáticas de la Universidad Autónoma de Madrid, donde el apoyo de los profesores responsables ha sido de gran valor para estos estudios. Congeladores y neveras han almacenado las muestras y diversos instrumentos de medida han podido ser empleados con enorme paciencia del resto de usuarios. En el despacho he tenido además la oportunidad de convivir en el proceso doctoral con otros doctorandos que han hecho el camino mucho menos aterrador. Gracias a Amanda, Conchi, María José, David, Marta, María, Marieke, Lucas y Luis del despacho de Ecología del Paisaje así como muchos otros del Departamento. Especialmente agradecido estoy al laboratorio de criptogámia del Prof. Francisco Lara donde un herbario de musgos antárticos ha empezado a constituirse.

En segundo lugar, e igualmente importante, ha sido el Laboratorio de Activación Inmunológica (en Majadahonda, Madrid) donde se pudieron diseñar desde cero y realizar todos los análisis de fauna gracias a la Dra. Pilar Lauzurica. como parte de mi primera estancia de investigación en 2011. Aquí no solamente encontré todo el soporte científico necesario para tal empresa sino que disfruté una tiempo magnifico en cada visita ya que el personal del laboratorio me ayudó de sobremanera en un ambiente desconocido para mí como es un laboratorio de bioquímica; gracias especialmente a Eli, Teresa, Laura, Almudena y Sheila. También quiero agradecer paralelamente al Dr. Andrés Barbosa del Museo de Ciencias Naturales de Madrid por su gran conocimiento y dirección en el área de avifauna marina que permitió diseñar las líneas de esta investigación, así como recolectar las muestras en campo, compañero de viajes y que además fue de gran ayuda para entender el conjunto del panorama antártico a través de los seminarios en el museo.

Otro lugar de importancia y gran recuerdo es el British Antarctic Survey (en Cambridge, Reino Unido) y sus miembros, con especial cariño a la oficina medioambiental donde llevé a cabo mi segunda estancia de investigación con el Dr. Kevin Hughes. La experiencia de trabajar con un gestor e investigador ambiental de una campaña tan ambiciosa como la británica es fundamental para el enriquecimiento de la tesis, dándome una perspectiva global de conservación en la Antártida, además de un grandísimo compañero. Finalmente dar afectuosamente las gracias a la Dr. Tina Tin que no solamente dio gran apoyo científico, sino también una ayuda continua con el lenguaje científico en inglés.

Otros muchos han hecho posible estos años de trabajo, pero siempre bajo el apoyo máximo de mis padres (Almudena y Luis), hermanas y otros familiares, en especial de la tía Ester. Gracias también a Tere y a sus padres por estar conmigo llevándome hasta el final. Así, de esta manera este viaje me ha conducido al presente documento que no sea considerado meramente una humilde contribución científica sino también una experiencia de vida impresa en mi memoria. A todos vosotros, muchas gracias.

Resumen

Introducción y objetivos

En las últimas décadas el interés por el continente antártico ha crecido notablemente, y con ello las presiones sobre este espacio. La contribución al conocimiento de fenómenos ambientales como el agujero de la capa de ozono o el cambio climático mediante la investigación en los Polos han tenido gran repercusión en los medios de comunicación, dando a conocer los valores científicos de la Antártida. La celebración del 50º aniversario del Tratado Antártico y la organización del Año Polar Internacional en el año 2007-08 han promovido e impulsado las investigaciones polares. A su vez el deseo de conocer y vivir las singularidades del continente blanco, con sus distintos valores naturales, paisajísticos e históricos, ha dado lugar a un rápido crecimiento del turismo antártico desde principios de los años noventa. En consecuencia la llegada continuada de personas y la expansión de las infraestructuras se han convertido en una amenaza que transforma los valores del continente, mientras los intereses extractivos permanecen latentes. Ante este panorama de cambio es necesario evaluar los beneficios y minimizar los costes que supone la presencia humana en la Antártida para asegurar su conservación.

En este contexto, la presente tesis tiene por objetivo estudiar distintas cuestiones sobre la problemática de la interacción del hombre y los ecosistemas antárticos terrestres. En primer lugar, analizar los impactos de la presencia y movilidad humana sobre distintos componentes de los sistemas terrestres, tales como la vegetación o las colonias de avifauna marina. En segundo lugar, sobre la homogeneización de la biota por la introducción de especies y la transformación del ambiente físico atribuida al cambio climático. En tercer lugar, sobre las presiones espaciales que dan lugar a los citados impactos en las zonas libres de hielo, centrándonos en las de investigación, particularmente en las zonas protegidas como máximo representante de los valores de la Antártida. Junto a estos, se señalan los costes globales en forma de huella de CO_2 y frente a ellos se discuten los beneficios científicos. Y en último lugar, explorar los retos de futuro y las estrategias alternativas de gestión para la llevar a cabo una efectiva protección ambiental.

Diseño y aproximaciones metodológicas

Para abordar estas cuestiones la tesis se constituye de 6 investigaciones independientes: (1º) sobre la vulnerabilidad al pisoteo de la vegetación criptógama, (2º) sobre el estado de una especie no nativa introducida, la *Poa Pratensis* en el área especialmente protegida Caleta Cierva (ASPA 124), (3º) sobre los niveles de estrés en pingüineras del género *Pygoscelis* en distintas colonias de la Antártida Marítima, (4º) sobre la distribución global de permisos a áreas antárticas especialmente protegidas, (5º) sobre la gestión de impactos en torno a un campamento remoto de investigación en el área especialmente protegida de Península Byers (ASPA 126), (6º) sobre los escenarios de futuro en el área especialmente administrada de Isla Decepción (ASMA 4).

Las distintas investigaciones se basan en la recogida in-situ y remota de datos para la elaboración de indicadores que permitan el entendimiento de los procesos. El diseño de las investigaciones especificas a través de la construcción de indicadores sigue distintos enfoques propios de la Ecología Recreativa, entre los que cabe destacar el desarrollo de estudios experimentales (aproximación de la investigación 1º), descriptivos (2º), comparativa (3º), seguimiento (4º y 5º) y simulación (6º). Como marco de referencia se sigue mayoritariamente el esquema de Fuerza Conductora-Presión-Estado-Impacto-Respuesta a fin de englobar e integrar los distintos aspectos antrópicos y ambientales que intervienen en las distintas cuestiones. Si bien, para explorar los retos de futuro se opta por la metodología de Evaluación de Ecosistemas del Milenio incidiendo más en la construcción de escenarios de futuro y alternativas de gestión.

Artículos y resultados

Las distintas investigaciones se plasman en una serie de artículos. **El primero** de ellos explora el impacto del pisoteo generado por las personas en comunidades dominadas por musgos y líquenes de la Antártida. Para ello, se llevó a cabo una simulación de pisoteo experimental en parcelas no afectadas previamente, caracterizadas por diferentes composiciones de plantas criptógamas terrícolas en la Península Byers. Todas las comunidades analizadas fueron extremadamente sensibles pero con distintos procesos de denudación observados. **El segundo trabajo** realiza un seguimiento a una colonia aislada de la hierba no-nativa, *Poa pratensis*, que fue introducida de manera inadvertida en la Caleta Cierva, Península Antártica, en el verano austral de 1954-55, y que sigue presente hoy en día tras una inspección en Febrero de 2012, convirtiéndola en la colonia persistente más antigua de una planta vascular no nativa de la Antártida. Las condiciones ambientales, en particular las bajas temperaturas del verano austral pueden estar inhibiendo la reproducción sexual. Igualmente se describe el riesgo ambiental que presenta la *Poa pratensis* y se defiende la necesidad de erradicar esta especie no-nativa con la mayor urgencia. **El tercer artículo** desarrolla el indicador corticosterona en plumas como una técnica no invasiva para el estudio del estrés en pingüinos de las tres especies del genero Pygoscelis en la Antártida Marítima. En el marco de la frecuente interacción entre humanos y colonias de aves marinas de la Antártida los presentes resultados arrojan una indicación sobre posibles molestias derivadas de las actividades antrópicas. **El cuarto estudio** evalúa la efectividad de los sistemas actuales de permisos e intercambio de información a través de examinar los datos aportados sobre visitas al repositorio del Tratado Antártico como Sistema de Intercambio de Información Ambiental entre las temporadas 2008/09 y 2010/11. Con la información disponible se observa como las estimaciones de ocupación de ASPAs varían notablemente entre regiones y según el objeto principal de protección. **El quinto artículo** examina la gestión ambiental del campamento español emplazado en la Zona Antártica Especialmente Protegida (ASPA) Nº 126 Península Byers, en la Isla Livingston, dentro del archipiélago de las Islas Shetland del Sur. Los resultados muestran el patrón de movimiento dentro del ASPA y como las actividades e impactos se concentran en torno al campamento. A través de la experiencia se discuten recomendaciones prácticas en las operaciones logísticas para minimizar los impactos y maximizar los beneficios científicos. **El sexto y último artículo** recopila los principales impactos ambientales y mecanismos reguladores en la isla antártica Decepción, a la vez que se examinan las tendencias e impulsores de cambio actuales junto con los escenarios alternativos de gestión futura. En este trabajo se postula un juego de equilibrios entre intereses en los que distintas políticas intermedias puedan tener un papel clave para la sostenibilidad a largo plazo

Discusión y conclusiones

Como ya se anticipaba, el continente se encuentra en cambio, un cambio gradual, en el que mientras los valores naturales y paisajísticos se deterioran otros valores legítimos crecen y se diversifican (valores científicos, educativos e históricos). La suma de estas alteraciones provoca sucesivamente cambios cada vez más profundos en lo que entendemos como el ambiente antártico. La contraposición de valores en la Antártida supone un dilema de prioridades entre el interés conservacionista, el interés científico y el interés educativo/cultural o recreativo. Ante una transformación progresiva, extendida en el tiempo y manifestada gradualmente, solamente podemos afrontarla pensando de antemano y actuando en conjunto, esto es integrando las distintas visiones en una estrategia global de gestión ambiental. De esta manera la presente tesis doctoral busca contribuir al conocimiento para contribuir a la protección ambiental de los ecosistemas antárticos.

Índice de contenidos

Listado de Publicaciones

El capítulo de zonas de estudio de la memoria de Tesis Doctoral incluye un trabajo previo de revisión de las investigaciones enmarcadas en la principal zona de trabajo, la Península Byers:

Benayas J, **Pertierra RL**. Tejedo P. Bermudez O. Lara F. Hughes KA. & Quesada A. (2013). A review of scientific research trends within ASPA 126 Byers Peninsula, South Shetland Islands, Antarctica. *Antarctic Science,* Aceptado: 21 Jul 2012. doi:10.1017/S0954102012001058.

El capítulo de resultados presentados en la memoria de Tesis Doctoral está compuesto por seis sub-capítulos que hacen referencia a los siguientes artículos, referenciados en el texto con los correspondientes números romanos:

I. **Pertierra RL**. Tejedo P. Lara F. Benayas J. & Quesada A. (2013) Fast denudation processes in cryptogam communities from Maritime Antarctica subjected to human trampling. Aceptado: 11 Jul 2012. *Antarctic Science* doi:10.1017/S095410201200082X.

II. **Pertierra RL.** Lara F. Hughes K. Benayas J. (En prensa) Non native grass *Poa pratensis* persisting for 70 years in Cerva Cove, Antarctic Peninsula. *Polar Biology.*

III. **Pertierra RL.** Justel A. Lauzurica P. Barbosa A. & Benayas J. (En preparación) Corticosterone in feathers: a non-invasive technique to measure stress levels on Antarctic penguins.

IV. **Pertierra RL**. & Hughes KA. (2013) Management of Antarctic Specially Protected Areas: permitting, visitation and information exchange practices. *Antarctic Science* Aceptado: 8 Oct 2012. doi:10.1017/S0954102012001204.

V. **Pertierra RL.** Hughes K. Benayas J. Justel A. & Quesada A. (2013) Environmental management of a scientific field camp in Maritime Antarctica: Reconciling research impacts with conservation goals in remote ice-free areas. *Antarctic Science* Aceptado: 29 Sept 2012. doi:10.1017/S0954102012001083.

VI. **Pertierra RL.** Tejedo P. & Benayas J. (2013) Chapter 8: Looking into the future of Deception Island: current status, drivers of change and policy alternatives. En: Antarctic futures: Human engagement with the Antarctic environment. *Eds.* Tin T. Lamers, Liggert D, M. Haase D. & Maher P. *Springer* Aceptado: 30 May 2012.

Finalmente en la relación de adjuntos se incluye el siguiente artículo previo (ver anexo I) que da pie a los trabajos del capítulo I y subsiguientes:

Tejedo P. **Pertierra RL**. Benayas J. Justel A. Quesada A. & Convey P. (2012) Trampling on Maritime Antarctica. Can soil ecosystems be effectively protected through existing codes of conduct? *Polar Research* 2012, 31, 10888, http://dx.doi.org/10.3402/polar.v31i0.10888.

Publicaciones relacionadas

A continuación se presenta el listado de colaboraciones en otras publicaciones directamente relacionadas con la tesis doctoral:

Pertierra RL. Tejedo P. Benayas J. & Boada M. (2011) Evolución del turismo en la Antártida. *Quercus,* 300*,* pp. 52-60. Febrero 2011.

Hughes KA. **Pertierra RL**. & Walton D. (En prensa) Management of Antarctic Specially Protected Areas: are our environmental practices adequate? *Environmental Science and Policy.*

Tejedo P. **Pertierra RL.** & Benayas J. (2012) Chapter 6: Trampling the Antarctic: consequences of human traffic on Antarctic soils. En: Antarctic futures: Human engagement with the Antarctic environment. *Eds.* Tin T. Lamers, Liggert D, M. Haase D. & Maher P. *Springer* Aceptado: 30 May 2012.

Lara, F. & **Pertierra LR.** (2012) *Brachythecium subpilosum* (Hook. f. & Wilson) 645 A. Jaeger. *In* ELLIS, L., *column ed. New National and Regional Bryophyte Records, 32. Journal of Bryology.*

Tejedo P. **Pertierra RL.** Benayas J. & Boada M. (2011) Equilibrios sobre el hielo: una breve pero completa revisión de los impactos de la actividad humana en la Antártida. *Ecosistemas* 20 (1): 69-86. Enero 2011 http://www.revistaecosistemas.net/articulo.asp?Id=681.

Barbosa, A., De Mas, E., Benzal, J., Diaz, J.I., Motas, M., Jerez, S., **Pertierra, RL.,** Benayas, J., Justel, A., Lauzurica, P., Garciapeña, F.J. & Serrano, T. (2013) Human Impact in Penguins: A comparison between a visited and a non-visted rookery. *Antarctic Science,* Aceptado 4 Jul 2012. doi:10.1017/S0954102012000739.

Contribución a Congresos:

- International Polar Year Oslo Open Science Conference. Oslo (Noruega), junio 2010.

  Presentación de la comunicación oral "*Indicator system for monitoring the human activity in Deception Island (Antarctica)*". Benayas, J., Justel, A., Boada, M., Pertierra, L. & Tejedo, P.

  Presentación de la comunicación oral "*The Effects of Trampling by Tourists on Maritime Antarctica Soils*". Tejedo, P., Pertierra, L., Justel, A. & Benayas, J.

- VIII Simposio Español de Estudios Polares. Palma de Mallorca, septiembre de 2011.

  Presentación del póster: "*Sensibilidad de la vegetación muscinal antártica al pisoteo*". Pertierra, L., Lara, F., Tejedo, P., Benayas, J. & Quesada, A.

  Presentación del póster: "*Balance ambiental del Campamento LIMNOPOLAR en Peninsula Byers, Isla Livingston*". Pertierra, L., Benayas, J., Justel, A. Tejedo, P. & Quesada, A.

  Presentación del póster: "*Valoración de la eficacia de los códigos de conducta destinados a la conservación de los suelos antárticos afectados por el pisoteo*". Tejedo, P., Pertierra, L., Benayas, J., Justel, A., Quesada, A. & Convey, P.

- SCAR Open Science Conference. Portland (USA), julio 2012

  Presentación de la comunicación oral: "Management of Antarctic Specially Protected Areas (ASPA): assessing the effectiveness of current permitting and information exchange practices". Pertierra, L. & Hughes KA.

  Presentación de la comunicación oral: "Trampling in Antarctica: consecuences of a miss-step?". Tejedo P, Pertierra, L. Justel A. & Benayas J.

Listado de acrónimos

ANT-ECO = State of Antarctic Ecosystems

ANT-ERA = Ecosystem Resilience and Adaptation

APECS = Association of Polar Early Scientists

ASMA = Antarctic Specially Managed Areas

ASPA = Antarctic Specially Protected

ASOC = Antarctic & Southern Ocean Coalition

ATCM = Antarctic Treaty Consultative Meeting

ATS = Antarctic Treaty Secretariat

BAS = British Antarctic Survey

COMNAP = Council of Managers of National Antarctic Programs

CCAMLR = Commission for the Conservation of Antarctic Marine Living Resources

CNDP = Centro Nacional de Datos Polares

CPE = Comité Polar Español

CEP = Committee of Environmental Protection

CORT = Corticosterone

EBA = Evolution and Biodiversity in the Antarctic

ERA = Environmental Risk Assessment

EIA = Environmental Impact Assessment

EIES = Environmental Information Exchange System

HSM = Historic Site & Monument

ISCIII = Instituto de Salud Carlos III

IAATO = International Asociation of Antarctic Tour Operators

IMO = International Maritime Organization

IPY = International Polar Year

IGY = International Geophysical Year

MEA = Millenium Ecosystem Assessment

NAP = National Antarctic Program

OSC = Open Science Conference

SCAR = Scientific Committee of Antarctic Researchers

SSSI = Sites of Special Scientific Interest

SPA = Specially Protected Areas

UAM = Universidad Autónoma de Madrid

Capítulo

1 Introducción

INTRODUCCIÓN

1.1. JUSTIFICACIÓN DE LA INVESTIGACIÓN

La Antártida, incluyendo el océano austral, es un continente vital para la ciencia. En primer lugar es clave para el entendimiento del estado general del planeta. Las condiciones simplificadas del sistema antártico conforman un laboratorio natural. Esto se debe por un lado al relativo aislamiento histórico respecto a la influencia del ser humano, unido a un ambiente de frio extremo que proporciona condiciones controladas. Fenómenos globales como el cambio climático o el agujero de la capa de ozono y otros muchos procesos físicos atmosféricos, terrestres u oceánicos pueden monitorizarse con precisión aquí y servir como sistema de alerta temprana para el resto del planeta (Convey 2003, Convey 2006, Hennion et al. 2006). Asimismo el estudio de las respuestas de los sensibles ecosistemas antárticos es un excelente indicador de cambios en la biosfera ante efectos como la introducción de especies, los cambios en el clima o la contaminación global (Bergstrom et al. 2006a). Pero no solamente puede entenderse la Antártida como un centinela de la salud de la Tierra. También nos revela aspectos de su pasado ya que contribuye notablemente al conocimiento de la evolución de las especies y los paleo-climas (Huiskes et al. 2006). La geología y estratigrafía de la Antártida a su vez nos informan sobre diversos procesos geológicos asociados a periodos glaciares e interglaciares a distintas escalas temporales, en especial sobre la deriva y aislamiento del continente y su relación con el resto de masas continentales en los últimos 30 millones de años (Bergstrom et al. 2006b). Es igualmente revelador el conocimiento creciente sobre las adaptaciones de los organismos al medio extremo como referencia a ambientes exo-planetarios así como para la biogeografía mundial rompiendo en algunos casos paradigmas del entendimiento sobre la distribución de la biodiversidad, y en especial en lo que concierne a los microorganismos de suelos y lagos (Hughes et al. 2006, López-Bueno et al. 2009). La biodiversidad antártica es fruto de su compleja y extrema historia, siendo clave para su desarrollo la existencia de hábitats disponibles, de procesos de colonización, establecimiento (pre-adaptación), aislamiento y evolución (Skotniki & Selkirk 2006, Steven and Hoggs, 2006, Bergstrom et al. 2006b).

El valor científico por el continente no es el primer ni el único sino uno más dentro de los crecientes intereses por la Antártida (Chown et al. 2012a). Ya en 1820 surgieron los intereses comerciales con la caza masiva de focas generando los primeros restos arqueológicos en el continente (Smith & Simpson XX). A finales del siglo XIX la industria ballenera vivió su máximo esplendor, y actualmente sus lugares de actuación se han convertido en enclaves de interés histórico (Dibbern et al. 2010). Tal vez el interés explorador de principios de siglo XX ha quedado relegado a un papel secundario tras la llamada Época Heroica. Sin embargo, su legado despierta un reseñable interés turístico encontrando varios sitios históricos entre los lugares más visitados (Pertierra et al. 2011). A su vez los amenazados ecosistemas polares despiertan una simpatía e interés creciente entre la población, tal vez consciente del riesgo de perder la oportunidad de ver el último lugar salvaje, hoy cada vez más deteriorado. El interés turístico y el valor educativo de la Antártida son un elemento en alza pero no los únicos. Aunque las disputas territoriales quedaron paralizadas tras la firma del tratado (ver más adelante) siguen hoy en día latentes. El crecimiento poblacional mundial, el agotamiento de recursos y la mejora de las tecnologías de prospección dentro del marco del cambio global agudizan el interés por los cada vez más codiciados recursos naturales de la Antártida (Chown et al. 2012a). En consecuencia la presencia humana en la Antártida y la presión por explotarla es cada vez mayor gracias entre otros aspectos a las mejoras tecnológicas que permiten acceder y permanecer en este espacio remoto. El turismo en la zona ha crecido notablemente en las últimas décadas (Enzenbacher 2007, Lynch et al. 2010). Asimismo nuevas naciones se van adhiriendo paulatinamente al tratado antártico y se diversifican las investigaciones e intereses de los países constituyentes (Jacobsson 2007). Debido al relativo aislamiento del continente la huella acumulada todavía es muy baja en muchas regiones, sin embargo la creciente historia de ocupación concentra cada vez más visitantes en las zonas más accesibles reduciendo la extensión de zonas vírgenes. En resumen, la Antártida congrega numerosos valores naturales de conservación, valores científicos, valores paisajísticos, educativos e históricos así como valores extractivos y de explotación. Todo estos servicios despiertan intereses contrapuestos que amenazan mutuamente los otros valores del continente (Chown et al. 2012a), por ello deben ser compatibilizados a nivel internacional.

Por el interés científico y conservacionista se debe tratar de preservar intacto el medio de estudio. Sin embargo las investigaciones en sí pueden llegar, en ciertos casos, a afectar inevitablemente al objeto de estudio o al entorno. Como ejemplo, puede señalarse el caso de la investigación en los grandes lagos antárticos subterráneos aislados bajo la plataforma de hielo (el Lago Vostok, o el Lago Ellsworth). Su estudio conlleva un gran riesgo de perturbarlos, por lo que se están buscando técnicas no intrusivas para su exploración aunque esto implica un cierto grado de incertidumbre. De tal manera los efectos indeseados deben ser controlados en toda investigación y minimizados a fin de proteger el medio para otras investigaciones presentes y futuras. Así el interés por preservar el espacio antártico como un lugar de referencia para diversas investigaciones y como patrimonio natural se ve paradójicamente amenazado por la creciente presencia de los propios investigadores y turistas. Encontrar el equilibrio de investigaciones y visitas es un reto clave para la conservación futura. Son necesarios estudios que detecten y desvelen la vulnerabilidad de los ecosistemas, el grado de afección y las posibles estrategias de minimización del impacto. En consecuencia, la presente investigación tiene como finalidad contribuir al conocimiento sobre el estado de los ecosistemas antárticos terrestres, la carga de presión humana, los impactos generados y los mecanismos de protección. Los distintos aspectos estudiados en el presente texto a través de objetivos específicos responden a necesidades concretas e inquietudes planteadas por investigadores y gestores en los sitios de estudio. De tal forma las presentes investigaciones pretenden servir a una doble finalidad, por un lado contribuir al conocimiento sobre la gestión de los impactos identificados, y por otro lado dar respuesta mediante medidas concretas de actuación que contribuyan a la minimización y control de estas alteraciones.

1.2 CONTEXTUALIZACIÓN

1.2.1 La firma del Tratado Antártico y las actividades legítimas

La conservación de la Antártida hoy en día se debe en gran medida al sistema del Tratado Antártico (ATS 2012a). La lucha por la soberanía antártica durante la primera mitad de siglo conduce a la firma del tratado en el año 1959. Así el tratado supone la congelación de la disputas territoriales, designando la Antártida como un lugar santuario para la paz y la ciencia (Bergstrom et al. 2006a). La investigación científica es un requisito fundamental para la adhesión al tratado junto con un libre intercambio de información para la cooperación. En consecuencia son designados como países de pleno derecho aquellos que desarrollen una actividad científica sobre el continente. La ciencia antártica se erige de esta forma como la principal justificación de la presencia de las naciones constitutivas. El interés científico por las regiones polares se sustenta con la celebración del Año Polar Internacional (IPY), organizado cada 50 años actualmente (siendo el último celebrado en el periodo 2007-08) y generando a raíz de este evento los cimientos de cooperación investigadora internacional. En 1957-58 tuvo un papel clave para la constitución del tratado siendo justamente los 12 países firmantes originales del Tratado Antártico de 1959 los implicados como parte de la organización del año geofísico internacional (YGS) a su vez inspirado en el anterior IPY de 1932-33. Simultáneamente y debido a la intensidad de la actividad científica surge en 1958 como ente integrador el comité científico internacional conocido como SCAR. A su vez se crea en 1988 el COMNAP como ente coordinador de la logística de los cada vez más complejos y numerosos programas nacionales. Destacar igualmente que el interés por la conservación y los usos científicos conduce rápidamente a la declaración de las primeros sitios especialmente protegidos (SPA) en 1961 y más adelante de una serie de sitios de especial interés científico (SSSI). Estos quedan hoy agrupados en el sistema de Sitios Antárticos Especialmente Protegidos (ASPAs) en el área del tratado que corresponde a las tierras y hielos por debajo de 60º latitud Sur (Hughes et al. en prensa).

Frente a los programas nacionales de investigación el turismo antártico aparece como una actividad comercial legitima que promueve la educación. A partir de los años noventa sufre un crecimiento exponencial (Pertierra et al. 2011). La Asociación Internacional de Tour Operadores Antárticos (IAATO) se constituye en 1991 para regular la creciente industria con el objetivo de fomentar la seguridad y el respeto al medio ambiente antártico. La auto-regulación de la industria es consecuencia de la falta de autoridades nacionales específicas para actividades comerciales en el ámbito antártico (Enzenbacher 2007). El acceso reiterado a una serie de sitios de visita por parte de la industria conduce a elaborar unas directrices de visita de los sitios más frecuentes para minimizar el impacto ambiental (IAATO 2011). Estas son una serie de notificaciones, recomendaciones y zonificaciones muy similares a los planes de gestión de áreas protegidas.

1.2.2 El impacto ambiental de la presencia humana en el continente

La presencia humana conlleva una alteración del medio antártico, el cual es considerado como paradigma del último ambiente prístino. Hull y Bergstrom (2006) engloban las amenazas para la conservación en cuatro grupos: (i) impactos locales y perdida de hábitat, (ii) homogenización de la biología (iii) efectos del cambio climático y (iv) extracción y extinción de recursos. Las amenazas en cuanto a su escala espacial y de gestión se pueden distinguir en globales (por ejemplo: cambio climático, agujero de ozono, contaminación mundial o sobrepesca oceánica) o bien locales / regionales (p.ej. introducción de especies invasoras, perturbaciones a fauna y vegetación nativa, caza y pesca intensiva o procesos de contaminación local) (Whinam et al. 2006). Las amenazas globales son relativamente homogéneas en torno a unas pocas regiones, mientras que las amenazas locales tienen una gran irregularidad espacial. El desarrollo histórico humano en la Antártida condiciona notablemente la distribución de actividades e infraestructuras. Aquí la accesibilidad es un factor clave tanto para presión como la protección. En consecuencia la presión es desigual con zonas bastamente abandonadas y otras con una notable concentración de infraestructuras humanas. En este contexto Tin et al. (2009) y Tejedo et al (2011) han realizado una minuciosa revisión de los impactos observados en la Antártida.

A escala global los impactos más importantes (entendidos a nivel de velocidad de degradación) por la presencia humana en la Antártida pueden considerarse la perdida de suelos y ambientes vírgenes (Hughes et al. 2011), las oscilaciones inducidas en poblaciones de fauna y flora por la caza histórica y la sobrepesca (Smith y Simpson 1987), las emisiones globales de CO_2 de los programas nacionales y turísticos (Farreny et al. 2011), la contaminación acumulada derivada de infraestructuras (sin estudios globales que conozcamos), y el cambio en la biodiversidad terrestre y marina por introducción y extinción local de especies (Frenot et al. 2005). A estos se suman los impactos mundiales igualmente presentes aunque no necesariamente originados en la Antártida. Entre estos cabe destacar los efectos derivados del cambio climático que inciden en la Antártida (Vaughan et al. 2003, Turner et al. 2005, Turner et al. 2009) provocando cambios en la fisiología y distribución de los organismos, así como pérdida de biodiversidad (Convey 2006). El calentamiento de la Antártida asociado a las emisiones globales de CO_2 es desigual, expresando los mayores incrementos en la región de la Península Antártica (Turner et al 2005, Vaughan et al. 2003). También cabe señalar la contaminación de las regiones pobladas trasmitida a través de la circulación de vientos y las cadenas tróficas marinas a los ecosistemas antárticos.

Los impactos globales son consecuencia en primer lugar del funcionamiento de infraestructuras como fuerzas generadoras (fundamente bases, estaciones de medida, campamentos y buques) (Tin et al. 2009) distribuidas por una serie de sitios y rutas por la Antártida (Hughes et al. en prensa, Lynch et al. 2009). La magnitud de los impactos deriva en primer lugar de los niveles de presión; esto es a través del número final de usuarios: científicos y técnicos en tierra como tripulaciones, científicos y turistas en mar, así como de las actividades individuales que desarrollan. Mientras que los turistas, técnicos y tripulaciones tienen unas localizaciones y actividades en principio más previsibles son las de los científicos las que presentan una mayor diversificación (vease Hughes et al. 2011). La ocupación de la Antártida se ha venido desarrollando con un marcado papel geopolítico. Dos regiones aglutinan la mayor parte de los Programas Nacionales Antárticos (NAPs): la Península Antártica y el Mar de Ross. En la primera numerosas estaciones científicas de pequeño tamaño se aglomeran en zonas próximas mientras que en la segunda aparecen unas pocas bases de gran tamaño que alojan centenares de científicos, siendo el caso más notable el de la estación estadounidense McMurdo con capacidad para más de 1.500 personas durante el verano antártico (COMNAP 2012). La Antártida Este es una región en colonización, con bases dispersas de países con fuertes programas logísticos (Suecia, Noruega, Francia, Australia, Sudáfrica). La Antártida Oeste es en cambio la región menos ocupada, posiblemente debido su lejanía con los continentes de origen y sus duras condiciones climáticas. De forma similar ocurre con la distribución de las ASPAs. Las áreas especialmente protegidas se aglutinan en torno a la Península Antártica y el Mar de Ross con algunas dispersas por la Antártida Este. La Antártida Oeste, vastamente desocupada, no presente ningún espacio protegido declarado. A su vez la mayoría de los sitios de visita turísticos se concentran en una ruta de entrada por las Islas Shetland del Sur y bajada por la Península Antártica cada vez más definida (Lynch et al. 2009). Por su parte en la zona del mar de Ross un grupo reducido de sitios históricos designados como ASPAs de interés educativo son visitados anualmente por un considerable número de turistas permitidos pese a acogerse como espacios protegidos (en otras regiones la entrada a las ASPAs queda limitada a investigadores y mediante un permiso individual). De tal forma existe una notable irregularidad espacial en el ordenamiento dispuesto por los países presentes en el continente.

En segundo lugar la magnitud de los impactos es consecuencia de la sensibilidad de los ecosistemas. Es importante señalar que la biogeografía de la Antártida debe entenderse como una red de "islas" de tierra rodeadas por agua o hielo (Chown y Convey 2006). Las zonas libres de hielo son precisamente los lugares más explotados por el ser humano pese a su escasez (con un área total estimada en cerca de 50.000 Km^2). Sin embargo, menos del 5% (aprox. 2.500 Km^2) aparecen protegidos. Aunque las zonas libres de hielo corresponden de forma natural a una fracción diminuta del continente, sin embargo contienen grandes valores naturales y científicos acogiendo a investigadores y turistas. Los programas nacionales encuentran aquí el lugar para el establecimiento de bases y campamentos. Por su parte los barcos turísticos acumulan sus desembarcos en estos espacios ya que la biología terrestre muestra aquí su mayor riqueza. Así, las zonas libres de hielo contienen muchos de los valores naturales de la Antártida que a su vez son vulnerables a las perturbaciones siendo el centro de atención de la presente tesis.

El primer elemento destacable en las zonas libres del hielo es la formación de suelos y los hábitats que generan. Los suelos sufren de inicio un impacto directo por el mero pisoteo que produce alteraciones de sus propiedades derivadas de la erosión y compactación (Ayres et al. 2008). Campbell et al. 1998 observaron en la zona de los Dry Valleys (región del Mar de Ross) la rápida formación de senderos a bajas concentraciones de pisoteo (a partir de tan solo 20 pisadas) así como una larga persistencia en ocasiones (más de 30 años). El pisoteo en los Dry Valleys parece afectar igualmente a las comunidades de nematodos incluso a bajas presiones, esto es, con una carga de 80 pasadas al año (Ayres et al. 2008) generando impactos visuales cuantificables (O'Neill et al 2010). Aspectos como variaciones en la biodiversidad nativa o la carga de introducción de especies no-nativas pueden medirse a través de la cuantificación de la abundancia/riqueza de colémbolos (Tejedo et al. 2005). Tejedo et al. 2009 encontraron un impacto significativo por pisoteo en las comunidades edáficas de colémbolos a partir de 100 pisadas con caída de la abundancia de individuos por superficie. De tal manera los colémbolos, un elemento conspicuo en la fauna edáfica, pueden considerarse buenos indicadores de perturbaciones a nivel del suelo debido a la presencia humana (Tejedo et al. 2013).

Un elemento frecuente en zonas libres de hielo es la presencia de colonias de mega fauna marina que encuentran aquí su hábitat de descanso y reproducción. Por ello la mega-fauna además de los impactos citados para la micro fauna, como la pérdida o transformación de hábitat es adicionalmente susceptible de sufrir perturbaciones por interacciones directas con el ser humano (Beale 2007). Al respecto las molestias locales a la fauna pueden modificar su conducta con efectos en su biología. Entre los impactos descritos en la Antártida se encuentra la trasmisión de enfermedades, un aumento del estrés de los individuos y la disminución de poblaciones, ya sea por caza directa o por efectos indirectos en la cadena trófica (De Villiers 2008). Entre estos los pingüinos han sido identificados como centinelas de los cambios en el medio antártico y pueden emplearse como indicadores (Boersma 2008). La mera presencia humana de manera reiterada puede generar un estrés crónico en las poblaciones de pingüinos con efectos fisiológicos (Villanueva *et al*. 2012). En el caso de la investigación el estrés podría ser más marcado por la mayor interacción con los animales (Vleck et al. 2000). Estos efectos fisiológicos tienen consecuencias negativas en la supervivencia y la reproducción (Walker *et al*. 2006).

La flora antártica terrestre reúne pocas especies de plantas vasculares (con solo dos especies nativas: *Deschampsia antarctica* y *Colobanthus quitensis*), en cambio la abundancia y extensión de criptógamas es mucho mayor (Sancho & Pintado 2011). Así el mundo vegetal en la Antártida está dominado principalmente por los hongos liquenizados, o líquenes, y por los briófitos (musgos y hepáticas), siendo (junto con *D. antarctica* y *C. quitensis*) las únicas plantas terrestres que en lugares propicios cubren, a modo de praderas, extensiones importantes de terreno libre de hielo en esta porción del planeta. Con cerca de 110 especies censadas en el continente, la diversidad de musgos antárticos es relativamente elevada, aunque todavía parcialmente conocida (Ochyra *et al*., 2008). Algunas especies son poco frecuentes o de crecimiento lento siendo especialmente vulnerables a las perturbaciones. Incluso un ligero incremento de temperaturas afecta al desarrollo y la respuesta metabólica de las plantas, en particular a la actividad fotosintética y la mayor disponibilidad de agua y liberación de nutrientes modificando el desarrollo normal y hábitat disponible convirtiéndolo en nicho para especies no indígenas (Hennion et al. 2006). El pisoteo de la vegetación antártica genera rápidamente una denudación de la vegetación. Al respecto en ambientes sub-antárticos se han detectado cambios en la composición de especies derivados del uso de senderos (Gremmen et al. 2003). La biodiversidad florística en las proximidades de las bases y en los sitios de visitas turísticas puede ser muy alta, tal como reflejan por ejemplo Sancho *et al*. (1999) en el entorno de la Bahía Sur, Isla Livingston, ubicación de la Base Juan Carlos I, por lo que es muy posible que las comunidades vegetales antárticas estén siendo afectadas por la creciente presión humana.

Finalmente la biodiversidad en conjunto (la citada fauna y flora así como la compleja microbiología) se ve amenazada por la llegada de propágulos de especies no nativas. En este aspecto la logística que requiere la investigación en estas zonas remotas del globo conlleva un alto riesgo de introducción de organismos no nativos (Hughes & Convey 2010). Esto determina que las regiones más pobladas tengan un mayor riesgo (Chown et al. 2012b). Aunque los protocolos de bioseguridad para evitar las bio-invasiones se han endurecido con el tiempo el incremento de las presiones y el debilitamiento de las barreras naturales por causa del cambio climático favorecen estos procesos de colonización. Esto destapa grandes cuestiones sobre los impactos de las introducciones en la interacción con la biología autóctona. En particular la microbiología de los suelos es quizás el grupo taxonómico peor estudiado (Cowan et al. 2011).

Con todos los elementos interconectados (esto es, la diversidad de actividades humanas con su variedad de presiones, frente a las sensibilidades singulares de los distintos componentes de los sistemas terrestres, dando lugar a los distintos impactos finales sobre estos ecosistemas) la protección final de las zonas libres de hielo encuentra numerosos retos para encontrar su adecuada conservación.

1.2.3 La investigación y gestión ambiental al sur del paralelo 60º

Para abordar la presente tesis es fundamental entender la singular condición del continente Antártico como un lugar devoto a "la paz y la ciencia" a través de un tratado internacional sin comparación. Los efectos administrativos derivados de la soberanía nacional son aquí distorsionados por la legislación comunitaria con todas sus implicaciones. La diplomacia tiene un papel esencial y por ello las estrategias de conservación basan su éxito en gran medida en la aceptación global de los países constitutivos. Hoy en día 28 países firmantes de pleno derecho del tratado tienen un representante en las reuniones anuales del tratado (ATCMs) en las que se decide sobre el sistema legal de gobierno conjunto de la Antártida (artículo 9). De esta forma la gestión de la Antártida tiene su máximo en las reuniones anuales de los países miembros. En estos encuentros se debaten y se aprueban nuevas determinaciones en torno al uso y la preservación de la Antártida por parte de las naciones constitutivas de pleno derecho. Previamente las naciones presentan documentos informativos y documentos de trabajo. Entre los temas más frecuentemente tratados en las últimas reuniones está la revisión de los planes de gestión de las áreas gestionadas o protegidas y las guías de visita de los sitios de interés turístico. También se presentan los informes anuales de la actividad de los programas nacionales en los que se detallan, entre otros, el número de permisos otorgados para acceder y tomar muestras en las ASPAs. Dentro del tratado se crea en 2003 la Secretaria del Tratado Antártico (ATS) como ente coordinador de las reuniones anuales (Vigni 2007).

El Protocolo de protección ambiental se elabora en 1991 (Web de la Secretaría del Tratado Antártico; 2012b) y se ratifica en 1998 para proteger y preservar el medio ambiente antártico. Asimismo se constituye desde ese momento el Comité de Protección Ambiental (CEP) como cuerpo de expertos que aconseja e instruye en cuestiones ambientales recogidas en el Protocolo Ambiental. Este comité se complementa con la Comisión para la Conservación de los Recursos Biológicos Marinos Antárticos (CCAMLR) fundado en 1982 en respuesta al agotamiento de kril antártico y que se centra en la protección de los organismos y ecosistemas marinos. La presencia humana legitima ya sea por ostentación territorial, ciencia o turismo queda regulada de forma más estricta a través del Protocolo. Las zonas de mayor protección e interés científico quedan unificadas como ASPAs mientras que las áreas de mayor complejidad logística se designan como ASMAs para promover la gestión conjunta. La entrada en las ASPAs queda limitada a personal permitido de acuerdo a los objetivos del plan de gestión de la zona. Por otro lado se exige una Evaluación de Impacto Ambiental de todas las actividades llevadas a cabo. Se promueve más aun el intercambio de información ambiental, culminando en la designación del sistema EIES en 2008 como el repositorio formal de intercambio obligatorio para los países consultivos y de forma optativa para el resto. El sistema contempla dos informes básicos, el informe pre-temporada que avisa de las actividades planeadas de un programa nacional para la siguiente campaña antártica, y el informe anual que detalla las actividades efectuadas durante la pasada campaña. En estos informes se incluye entre otros el listado de permisos otorgados para el acceso a ASPAs y el número de personas que acceden. El tratado antártico tiene aun por abordar la conexión entre problemas locales como la introducción de especies y los problemas globales, como puedan ser los efectos potenciadores derivados del cambio climático (Hull & Bergstrom 2006).

Las propuestas en forma de documentos informativos y documentos de trabajo a las reuniones ATCM permiten tomar medidas y resoluciones paliativas (Dudeney & Walton 2012). Estas a su vez pueden servir como información de referencia en la futura preparación de planes de gestión de áreas protegidas, directrices de visita en sitios turísticos, paquetes de gestión en ASMA o protocolos básicos. Este primer mecanismo es óptimo para llamar la atención sobre aspectos de carácter general aplicables a distintos espacios o bien sobre espacios y casos concretos que carecen de mecanismos reguladores como puedan ser espacios amenazados carentes de protección Por ejemplo, sitios de visita y zonas de sacrificio entorno a bases. También es el lugar apropiado para iniciar y desarrollar protocolos generales de prevención así como evaluar la efectividad de los mecanismos pre-existentes. En el caso de espacios con una regulación específica tipo ASMA o ASPA existen formulas concretas. En el caso de zonas protegidas estas están sujetas a una revisión y actualización de sus planes de gestión. La participación directa en la revisión de un ASPAs presentando información relevante del sitio a los responsables del país designatario permite proporcionar conocimiento adicional sobre el espacio y preparar medidas concretas para ser incluidas directamente en los planes de gestión de forma que sean valoradas, aprobadas y finalmente incorporadas como parte del plan renovado en las reuniones del tratado. En el caso de las zonas especialmente gestionadas se produce igualmente una revisión periódica, en este caso del paquete de gestión. El paquete incorpora planes generales así como protocolos específicos y códigos de conducta. Los grupos de gestión en ASMAs son los comités responsables de áreas potencialmente conflictivas. La elaboración de propuestas por estos grupos permite un debate y acuerdo previo a formularlas directamente en las reuniones del tratado. De esta forma adquieren una mayor fuerza a la hora de ser valoradas y aprobadas en las reuniones.

Dentro de la gestión antártica la información científica tiene un papel asesor fundamental. En este sentido el SCAR es el ente promotor y coordinador de las actividades científicas en la Antártida. De tal forma el último programa estratégico del SCAR, denominado EBA (Evolución y Biodiversidad en la Antártida) tenía entre sus objetivos fundamentales: 1) estudiar el comportamiento de los organismos ante los cambios ambientales presentes y futuros y 2) identificar aspectos relevantes para las políticas de conservación y trasmitirlos al gobierno del Tratado Antártico. Para ello se crearon distintas bases de datos, censos y sistemas de monitoreo de los organismos y sistemas naturales; así como mecanismos de colaboración e internalización. Una de las aportaciones destacables del SCAR aplicable en el marco de la tesis es el código de conducta SCAR (2009) en el que se establecen directrices generales para reducir el impacto ambiental de los investigadores. Actualmente se han puesto en marcha dos nuevos programas gemelos: Ant-ECO (dedicado al conocimiento sobre el estado de los ecosistemas) (SCAR 2012a) y Ant-ERA (dedicado al estudio de la resiliencia de los ecosistemas) que pretenden dar continuidad a EBA y abrir nuevos desarrollos en cuestiones emergentes para la conservación (SCAR 2012b).

1.3 OBJETIVOS DE LA TESIS

El **objetivo general** de la presente tesis es ***contribuir a la conservación de la Antártida analizando distintos problemas ambientales actualmente vigentes, generando un mejor conocimiento relativo a los impactos ambientales derivados de la presencia humana en los sistemas antárticos terrestres y profundizando en los mecanismos de protección necesarios para su gestión***.

Los objetivos específicos del trabajo son:

1. Estudiar los impactos locales y la pérdida de hábitat a través de las perturbaciones generadas por la propia presencia humana sobre la biología de las comunidades nativas de fauna y flora terrestre.

2. Analizar los efectos de homogeneización de la biota a través de evaluar el riesgo de establecimiento y colonización de especies no nativas como amenaza para la biodiversidad natural en el contexto del cambio climático.

3. Identificar la huella humana y la problemática subyacente en los espacios terrestres protegidos como baluartes de la conservación en la Antártida así como cuantificar los costes globales y locales de la investigación antártica.

4. Explorar estrategias de gestión de impactos y optimización de las actividad humanas en zonas libres de hielo, analizar los modelos de gestión en el marco del tratado antártico y construir los escenarios de futuro alternativos existentes para la conservación de los valores protegidos

Para afrontar dichos objetivos específicos se han realizados seis investigaciones independientes (ver sección de Publicaciones) que toman forma en las secciones correspondientes del capítulo dedicado a los resultados. Cada estudio está dedicado a una tarea concreta:

- Estudiar los efectos del pisoteo sobre comunidades características de la vegetación terrestre en la Antártida Marítima potencialmente vulnerables a las perturbaciones (capítulo 4.1)
- Evaluar el estado reproductivo actual y el riesgo futuro de expansión de una especie no-nativa introducida accidentalmente en la Antártida Marítima respecto a las condiciones del microambiente en el sitio de introducción (capítulo 4.2)
- Medir los niveles de estrés en varias colonias y especies de pingüino para evaluar los posibles factores responsables, tales como distintas condiciones ambientales o los niveles de presencia humana (capítulo 4.3)
- Analizar la carga de presión humana en la red de espacios protegidos antárticos a través del sistema de permisos de entrada y el repositorio para el intercambio de información ambiental (capítulo 4.4)
- Evaluar los costes ambientales de la investigación antártica a través del seguimiento del ciclo de funcionamiento de un campamento temporal dentro de un área protegida (capítulo 4.5).
- Analizar los modelos de gestión y escenarios de futuro en un área antártica especialmente administrada aplicando las pautas del modelo de Ecosistemas del Milenio (capítulo 4.6)

1.4 PLANTEAMIENTO GLOBAL DE LA INVESTIGACIÓN

La presente tesis para la consecución de los objetivos específicos definidos se ha construido en primer lugar a través de tres campañas de investigación antártica (2009-10, 2010-10, 2011-12) en la que se han realizado varias expediciones e inspecciones a tres áreas protegidas (ASPAs 126, 134, 140), a un área administrada (ASMA Nº4), y múltiples zonas humanizadas (entorno de bases científicas y sitios de visita) que requieren de una gestión especial. Estas expediciones han permitido llevar a cabo distintos trabajos específicos de medición y análisis de datos en campo así como toma de muestras para trabajos en laboratorio. El trabajo se complementa asimismo con un análisis bibliográfico de las áreas centrales y objetos de estudio, en particular de la Península Byers (ASPA 126). Igualmente se han realizado dos estancias de investigación para cubrir distintas investigaciones. Finalmente se ha participado y realizado la defensa de los trabajos en los foros científicos nacionales e internacionales tales como los congresos Oslo IPY-OSC (2010) y Portland SCAR-OSC (2012), así como en el VIII Simposio de estudios Polares en Mallorca (2011). Todo ello para dar lugar a una serie de publicaciones y propuestas presentadas al Tratado Antártico que contribuyan al conocimiento y conservación de los ecosistemas antárticos.

A continuación se presenta el esquema que marca la integración de los distintos capítulos de resultados, así como una breve justificación de los objetivos específicos abordados en cada uno de ellos y la coherencia entre los mismos (Fig. 1.1)

Investigación 1. Estudio de los efectos del pisoteo en la vegetación terrestre La llegada de toda clase de visitantes conlleva el pisoteo de los suelos antárticos, siendo uno de los primeros impactos en ocasionarse y uno de los más evidentes. Por ello cabe plantearse que comunidades terrestres son las más sensibles al pisoteo en estos ambientes y cuanta presión son capaces de soportar, así como identificar los factores que afectan a este proceso de degradación y de qué manera. También deben identificarse aquellas estrategias básicas que pueden establecerse para minimizar los impactos debidos al tráfico de visitantes a pie en las zonas libres de hielo de la Antártida. Los estudios de impacto por pisoteo son una continuación de los trabajos iniciados por Tejedo y colaboradores (Tejedo et al. 2005. 2009, 2013). Para este aspecto se detectaron los aspectos inexplorados y las nuevas cuestiones que surgieron a raíz de los anteriores trabajos desarrollados sobre el tema. Un aspecto clave emergente en la conservación de los sistemas terrestres es la determinación de la vulnerabilidad de las comunidades terrícolas con definición de su capacidad de carga y las estrategias adecuadas a cada intensidad de tráfico sobre estas. Con este objetivo, se dirigieron las investigaciones hacia la identificación de aquellas comunidades vegetales terrestres más sensibles y la propuesta de estrategias eficaces de minimización de impactos.

Investigación 2. Evaluación del riesgo de expansión de una especie no-nativa La presencia humana conlleva el riesgo de introducción accidental de agentes extraños al medio antártico, incluyendo propágulos de especies no nativas. El continente antártico se caracteriza por la casi absoluta ausencia de plantas vasculares, con sólo 2 especies nativas, facilitando el seguimiento de las bio-invasores en este grupo taxonómico. Este objetivo busca establecer qué riesgo hay de introducción y persistencia de plantas vasculares a través de un caso de estudio, así como definir las barreras naturales operantes. Esta investigación analiza el riesgo de establecimiento y expansión de una especie vascular no nativa en Caleta Cierva. El estudio del estado fisiológico y fenológico de la planta nos permite situar su estado actual y estimar el riesgo futuro de una proliferación mayor. La falta de conocimiento sobre su estado desde el último informe en 1991 sobre la planta planteaba la necesidad de una inspección actualizada.

Investigación 3. Monitorización del estrés ocasionado por presencia humana en pingüineras La presencia del hombre en las zonas libres de hielo conlleva a su vez con una interacción frecuente con la fauna local, incluyendo la mega-fauna. En este caso, se ha desarrollado un estudio para tratar de valorar las molestias producidas en colonias de pingüino por distintas actividades humanas. Para evaluar el efecto inmediato de la mera presencia humana se optó por iniciar un seguimiento a través de un parámetro indicador de los niveles de estrés. Este análisis se realizó en las tres especies existentes de pingüinos Pygoscelidos. No se trata de cuantificar el perjuicio final sobre los individuos sino obtener una valoración de si existen efectos observables tales como una variación de los niveles de corticosterona. Se aplicó una técnica novedosa para desarrollar un indicador de estrés en pingüinos que permita detectar posibles efectos de la presencia humana. Se seleccionó la extracción de corticosterona en pluma de los individuos como una técnica aplicada con éxito en otras aves. De esta forma la presente investigación se encuentra en una fase temprana centrándose primeramente en el monitoreo del estado de los animales en distintas colonias para evaluar la variabilidad y los posibles factores responsables.

Investigación 4. Análisis el sistema de otorgamiento de permisos en ASPAS La entrada en las ASPAs queda regulada por la solicitud de permisos para realizar actividades recogidas dentro del plan de gestión. Estos permisos son otorgados por la autoridad nacional competente. En este sentido existe un mecanismo oficial de intercambio de información que recopila información sobre las actividades de los programas nacionales, el repositorio EIES. A través de la información disponible se busca evaluar en qué grado los programas nacionales implementan estos mecanismos, y asumiendo esta información conocer la distribución actual de visitas a zonas protegidas de la Antártida.

Investigación 5. Evaluación de los costes ambientales de un campamento en un ASPA. La investigación es una de las pocas actividades permitidas en las áreas especialmente protegidas. La diversidad de investigaciones y países e instituciones implicadas plantea retos de coordinación de actividades para la conservación del lugar. El siguiente objetivo consiste en recopilar y analizar la información disponible sobre actividad humana e impactos de un campamento en un área protegida, la Península Byers ASPA 126, así como definir cuáles son las estrategias de gestión de impactos y finalmente, identificar y valorar los beneficios científicos de la investigación en áreas protegidas. Esta investigación se complementa con una búsqueda previa y análisis bibliométrico de publicaciones en la zona (ver Benayas et al. (2013) en zonas de estudio, apartado 2.2). Mientras el citado estudio previo cuantifica la producción científica en la Península esta investigación recoge los costes de tales actividades a través del seguimiento ambiental al ciclo de vida de un campamento en el ASPA.

Investigación 6. Construcción de estrategias de gestión en un ASMA (capítulo VI) Las áreas especialmente administradas congregan gran número de valores protegidos, su declaración busca afrontar los posibles conflictos generados entre los distintos grupos con intereses, en ocasiones opuestos, en la zona (conservacionistas, investigadores, estratégicos, comerciales y recreativos). En el caso de la Isla Decepción todos estos aspectos aparecen recogidos y son tratados de manera colectiva por el grupo de gestión conformado por representantes de los países implicados en la gestión del ASMA. Sin embargo el crecimiento de intereses y las progresivas transformaciones del medio amenazan el modelo actual. De tal forma conocer el desarrollo histórico de la Isla Decepción y los impulsores de cambio actuales nos sirve como modelo de referencia para plantear escenarios de futuro alternativos y discutir la efectividad en la implementación de futuras medidas de conservación. De esta manera se busca afrontar de antemano la problemática de la protección frente a impactos acumulativos.

Integración de resultados. El capítulo final de discusión integra los resultados de los trabajos previos y los enmarca dentro del conocimiento actual sobre la conservación de la Antártida, señalando sus aportaciones y las cuestiones emergentes derivadas de ellas. Finalmente, se presentan las principales conclusiones derivadas de la investigación.

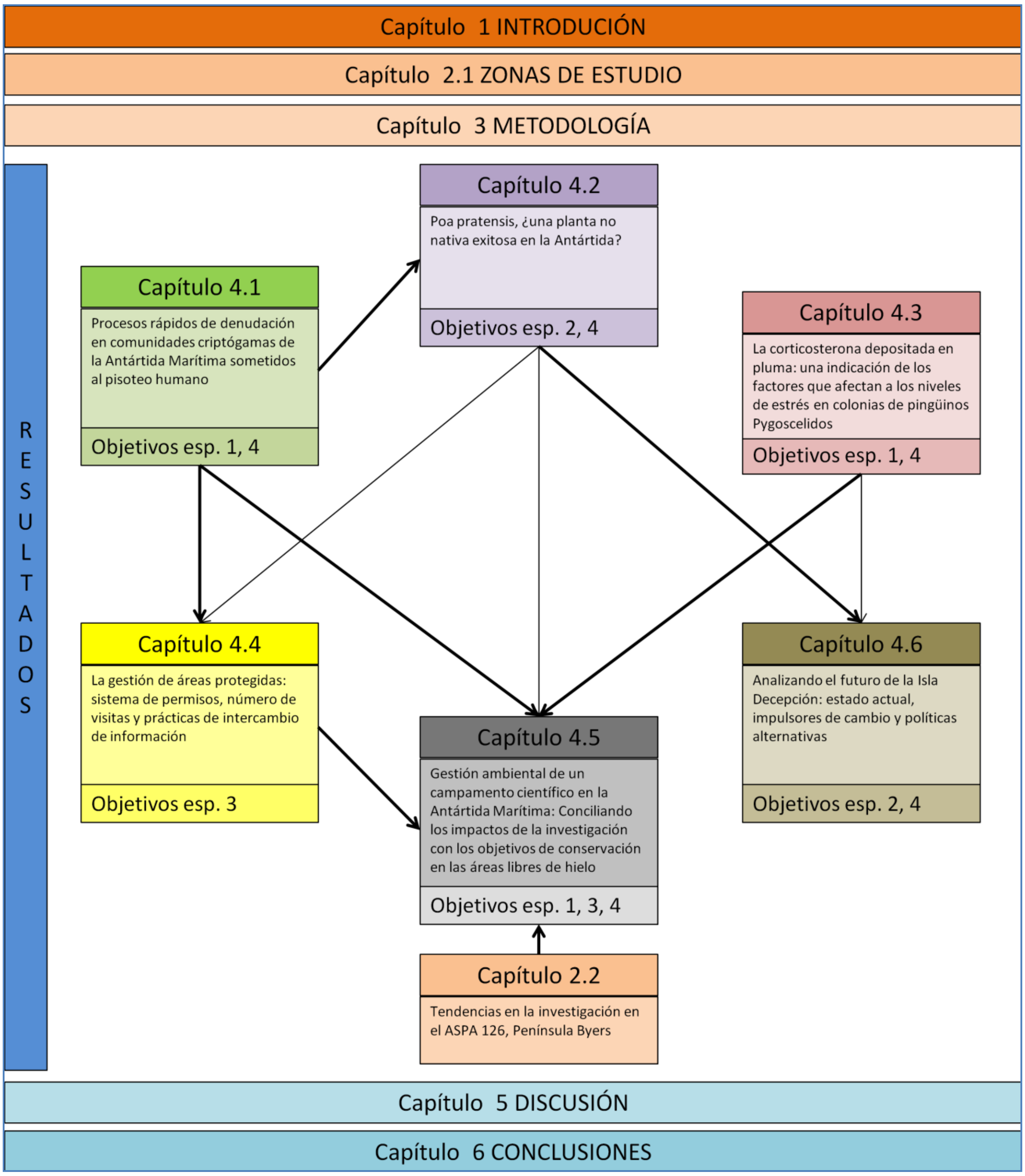

Figura 1.1. Esquema estructural del cuerpo de la Tesis Doctoral, con sus elementos transversales y englobados, en particular se detallan las 6 investigaciones independientes desarrolladas en relación con los objetivos específicos abordados en cada uno de las mismas, así como sus principales interacciones.

REFERENCIAS BIBIOGRÁFICAS DEL CAPITULO

- ATS (ANTARCTIC TREATY SECRETARIAT). 2012a. The Antarctic Treaty; Documentos; Antarctic Treaty; URL: http://www.ats.aq/documents/ats/treaty_original.pdf. Visitado por última vez en Nov. 2012.
- ATS (ANTARCTIC TREATY SECRETARIAT). 2012b. The Antarctic Treaty; Documents; Environmental Protocol. URL: http://www.ats.aq/documents/recatt/Att006_e.pdf). Visit ado poor ultimo vez en Nov. 2012.
- Ayres, E., Nkem, J.N., Wall, D.H., Adams, B.J., Barrett, J.E., Broos, E.J., Parsons, A.N., Powers, L.E., Simmons, B.L. & Virginia, R.A. 2008. Effects of human trampling on populations of soil fauna in the McMurdo Dry Valleys, Antarctica. Conservation Biology, 22, 1544-1551.
- Beale 2007. The Behavioral Ecology of Disturbance Responses. International Journal of Comparative Psychology, 2007, 20, 111-120.
- Bergstrom, D.M., Huiskes, A.H.L., Convey, P. (2006a) The Antarctic: local signals, global messages. In: Bergstrom, D.M., Convey, P., Huiskes, A.H.L. (ed.) in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator 339-345
- Bergstrom, D.M., Hodgson, D.A., Convey, P. (2006b) The physical setting of the Antarctic. Bergstrom, D.M., Convey, D.M., Huiskes, A.H.L. (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator 15-33
- Benayas J, Pertierra RL. Tejedo P. Bermudez O. Lara F. Hughes KA. & Quesada A. (2013). A review of scientific research trends within ASPA 126 Byers Peninsula, South Shetland Islands, Antarctica. Antarctic Science, doi:10.1017/S0954102012001058.
- Boersma 2008. Penguins as marine sentinels. Bioscience 58, 597-607
- Campbell I.B. G.C.C Claridge & M.R Balks 1998 Short- and long-term impacts of human disturbances on snow-free surfaces in Antarctica. Polar Record 34 (188): 15-24 (1998).
- Chown, S.L., Lee, J.E., Hughes, K.A., Barnes, J., Barrett, P.J., Bergstrom, D.M., Convey, P.,Cowan, D.A., Crosbie, K., Dyer, G., Frenot, Y., Grant, S.M., Herr, D., Kennicutt II, M.C., Lamers, M., Murray, A., Possingham, H.P., Reid, K., Riddle, M.J., Ryan, P.G., Sanson, L., Shaw, J.D.,Sparrow, M.D., Summerhayes, C., Terauds, A., Wall, D.H. (2012a) Challenges to the Future Conservation of the Antarctic. Science 337(6091). 158-159
- Chown SL Huiskes AHL Gremmen NJM Lee JE Terauds A Crosbie K Frenot Y Hughes KA Imura S Kiefer K Lebouvier M Raymond B Tsujimoto M Ware C Van De Vijver B & Bergstrom DM (2012b) Continent-wide risk assessment for the establishment of non indigenous species in Antarctica. Proceedings of the National Academy of Sciences, 109, 4938-4943.
- Chown, S.L., & Convey, P., (2006) (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator
- COMNAP (Council of Managers of Antarctic National Programs). 2012. List of Antarctic facilities. https://www.comnap.aq/Members/Shared%20Documents/Antarctic_Facilities_List_1April2012.xls
- Convey, P. (2003) Maritime Antarctic climate change: signals from terrestrial biology Antarctic Research Series 79. 145-158
- Convey P. (2006). Antarctic Climate change and its influence on terrestrial ecosystems, in Bergstrom, P. Convey and A.H.L. Huiskes (eds.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. Springer, Dordrecht.
- Cowan, D.A. Chown, S.L. Convey, P. Tuffin, M. Hughes, K.A. Pointing, S. Vincent W.A. 2011. Non-indigenous microorganisms in the Antarctic: assessing the risks Trends in Microbiology, Volume 19, Issue 11, pp. 540-548.

- Dibbern S.J. 2010. Fur seals, whales and tourists: a commercial history of Deception Island, Antarctica. Polar Record 46 (238): 210–221 (2010)
- De Villiers M. 2008 Review of recent research into the effects of human disturbance on wildlife in the Antarctic and sub-Antarctic region. In Human disturbance to wildlife in the broader Antarctic region: a review of findings. Appendix 1, Working Paper 12 for XXXI Antarctic Treaty 754 Consultative Meeting, Kiev, Ukraine, 2–13 June 2008.
- Dudeney J.R. & David W.H. Walton D.W.H. 2012 Leadership in politics and science within the Antarctic Treaty. Polar Research 2012, 31, 11075
- Enzenbacher, D. (2007). Antarctic Tourism Policy-making: Current Challenges and Future Prospects. In: TRIGGS, G. & RIDDELL, A. (eds.). Antarctica: legal and environmental challenges for the future. London: The British Institute of International and Comparative Law. pp. 155-189.
- Farreny, R., Oliver-Solà, J., Lamers, M., Amelung, B., Gabarrell, X., Rieradevall, J., Boada, M. & Benayas, J. 2011. Carbon dioxide emissions of Antarctic tourism. Antarctic Science, 23, 556-566.
- Frenot, Y., Chown, S.L., Whinam, J., Selkirk, P., Convey, P., kotnicki, M. & Bergstrom, D. 2005. Biological invasions in the Antarctic: extent, impacts and implications. Biological Reviews, 80, 45-72.
- Gremmen, N.J.M. Smith, V.R. & Van Torengen, O.F.R. 2003. Impact of trampling on the vegetation of Subantarctic Marion Island. Arctic, Antarctic, and Alpine Research, 35, 442-446.
- Hennion, F., Huiskes, A.H.L., Robinson, S., Convey, P. (2006) Physiological traits of organisms in a changing environment. In: Bergstrom, D.M., Convey, P., Huiskes, A.H.L. (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. 127-157
- Hughes, K.A, Ott, S., Bölter, M., Convey, P. (2006) Colonization processes. In: Bergstrom, D.M., Convey, P., Huiskes, A.H.L. (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. 35-55
- Hughes, K.A. 2010. How committed are we to monitoring human impacts in Antarctica? Environmental Research Letters, 5 041001.
- Hughes, K.A. & Convey, P. 2010. The protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. Global Environmental Change, 20, 96-112.
- Hughes, K.A, Fretwell p. Rae j. Holmes k. & Fleming A. 2011 Untouched Antarctica: mapping a finite and diminishing environmental resource. Antarctic Science, 23, 537-548.
- Hughes KA. Pertierra RL. & Walton D. (En prensa) Management of Antarctic Specially Protected Areas: are our environmental practices adecuate? Environmental Science and Policy
- Huiskes, A.H.L., Convey, P., Bergstrom, D.M. (2006) Antarctica as a global indicator: An introduction. In: Bergstrom, D.M., Convey, P., Huiskes, A.H.L. (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. 1-13
- Hull & Bergstrom, D.M. (2006) In: Bergstrom, D.M., Convey, P., Huiskes, A.H.L. (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator.
- IAATO (Internation Association of Antarctic Tour Operators). 2011. Guidelines for visitors to the Antarctic. http://iaato.org/es/visitor-guidelines. Visitado por última vez en Jun. 2012.
- Jacobsson (2007). The Antarctic Treaty System: Legals and Environmental Issues, Future Challenges for the Antarctic Treaty System. In: TRIGGS, G. & RIDDELL, A. (eds.). Antarctica: legal and environmental challenges for the future. London: The British Institute of International and Comparative Law. pp. 155-189.
- Lopez-Bueno, A., Tamames, J., Velazquez, D., Moya, A., Quesada, A. and Alcami, A. (2009) High Diversity of the Viral Community from an Antarctic Lake. Science 326(5954), 858-861.
- Lynch, H.J., Crosbie, K., Fagan, W.F. & Naveen, R., 2009. Spatial patterns of tour ship traffic in the Antarctic Peninsula region. Antarctic Science, 22(2), pp. 123-130

- Ochyra, R., R.I. Lewis & H. Bednarek-Ochyra. (2008). The Illustrated Moss Flora of Antarctica. Cambridge University Press, 685 pp.
- Olech M (1996) Human impact on terrestrial ecosystems in west Antarctica. Proc NIPR Symp Polar Biol 9:299–306
- O'Neill T.A., Balks M.R. & López-Martínez J. 2010: A provisional method for assessing the impact on, and recovery of, Antarctic Desert Pavements from human-induced disturbances. In R.J. Gilkes & N. Prakongkep (eds.): 32 Proceedings of 19th World Congress of Soil Science: Soil Solutions for a Changing World. 1-6 August 2010, Brisbaine, Australia.
- Pertierra L. Tejedo P. Benayas J. & Boada M. 2011. Evolución del turismo antártico: distribución, impactos y tendencias. Quercus, Nº 300, Febrero 2011. Ed. America Iberica.
- SCAR (Scientific Committee of Antarctic Research). 2009. Environmental code of conduct for terrestrial scientific field research in Antarctica. SCAR International Webpage. http://www.scar.org/researchgroups/lifescience/Code_of_824 Conduct_Jan09.pdf.
- SCAR (Scientific Committee of Antarctic Research). 2012a. Antarctic Thresholds - Ecosystem Resilience and Adaptation (AnT-ERA). SCAR Science & Data. http://www.scar.org/researchgroups/progplanning/#AntEco
- SCAR (Scientific Committee of Antarctic Research). 2012b. State of the Antarctic Ecosystem (AntEco). http://www.scar.org/researchgroups/progplanning/#AntEco
- Sancho, L.G., Schulz, F., Schoeter, B. & Kappen, L. (1999). Bryophyte and lichen flora of South Bay (Livingston Island: South Shetland Islands, Antarctica). Nova Hedwigia, 68(3-4): 301-337.
- Sancho, L.G. & Pintado A. (2011). Ecología vegetal en la Antártida. Ecosistemas 20(1):42-53.
- Smith, R.I.L. & Simpson, H.W. 1987. Early nineteenth century sealer refuges on Livingston Island, South Shetland Islands. British Antarctic Bulletin, 74, 49-72.
- Tejedo, P., Justel, A., Rico, E.,. Benayas, J., & Quesada, A 2005. Measuring impacts on soils by human activity in an Antarctic Special 803 Protected Area. Terra Antarctica Reports, 12, 57–62.
- Tejedo, P., Justel, A., Benayas, J., Rico, E., Convey, P. & Quesada, A. 2009. Soil trampling in an Antarctic Specially Protected Area: tools to assess levels of human impact. Antarctic Science, 21, 229–236.
- Tejedo P. Pertierra L. Benayas J. & Boada M. 2011 Equilibrios en el hielo, una breve pero completa revisión de los impactos humanos en la Antártida. Ecosistemas (1) pp. 69-86. Enero 2011.
- Tejedo, P., Pertierra L.R,, Justel, A., Benayas, J. Convey, P. & Quesada, A. 2013. Trampling on Maritime Antarctica: Can soil ecosystems be effectively protected through existing codes of conduct? Polar Research, accepted May 2012.
- Tin, T., Fleming, Z.L., Hughes, K.A., Ainley, D.G., Convey, P., Moreno, C.A., Pfeiffer, S., Scott, J. & Snape, I. 2009. Impacts of local human activities on the Antarctic environment. Antarctic Science, 21, 3-33.
- Turner, J, Colwell, S.R. MARSHALL, G.J. Lachlan-Cope, T.A. Carleton, A.M. Jones, P.D. Lagun, V. Reid P.A. & Iagovkina S. (2005) Antarctic climate change during the last 50 years. Int. J. Climatol. 25: 279–294 (2005)
- Turner, J., Bindschadler, R. A., Convey, P., Di Prisco, G., Fahrbach, E., Gutt, J., Hodgson, D. A., Mayewski, P. A. & Summerhayes, C. P. (Eds.) (2009). Antarctic Climate Change and the Environment. Cambridge: Scientific Committee on Antarctic Research.
- Skotnicki ML & Selkirk PM (2006) Plant biodiversity in a extreme environment. In: Bergstrom, D.M., Convey, P., Huiskes, A.H.L. (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. 161-176
- Steven MI & Hogg ID. (2006) The Molecular Ecology of Antarctic Terrestrial and Limnetic Invertebrates and Microbes. In: Bergstrom, D.M., Convey, P., Huiskes, A.H.L. (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. 178-193

- Vaughan, D.G., Marshall, G.L., Connolley, W.L., Parkinson, C., Mulvaney, R., Hodgson, D.A., King, J.C., Pudsey, C.J. & Turner, J. 2003. Recent rapid regional climate warming on the Antarctic Peninsula. Climatic Change, 60, 243-274.
- Villanueva, C., Walker, B.G. & Bertelloti, M. 2012. A matter of history: effects of tourist on physiology, behaviour and breeding parameters in Magellanic penguins (Spheniscus magellanicus) at two colonies in Argentina. Journal of Ornithology, 153, 219–228.
- Vigni 2007 The Secretariat of the Antarctic Treaty: Achievements and Weaknesses three years after its stablisment. In: TRIGGS, G. & RIDDELL, A. (eds.). Antarctica: legal and environmental challenges for the future. London: The British Institute of International and Comparative Law. pp. 155-189.
- Vleck, M., Bucherw, T. L.. Reed L., & Kristmundsdot A.Y. 1999. Changes in reproductive hormones and body mass through the reproductive cycle in the AdClie Penguin (Pygoscelis adeliae), with associated data on courting-only individuals. Proc. Int. Ornithol. Congr. 22:1210-1223.
- Walker, B.G., Boersma, P.D. & Wingfield, J.C. 2006. Habituation of adult magellanic penguins to human visitation as expressed through behavior and corticosterone secretion. Conservation Biology, 20, 146–154.
- Whiman J. Copson G. & Chapius J.L. (2006) Sub-antarctic terrestrial conservation and management. In: Bergstrom, D.M., Convey, P., Huiskes, A.H.L. (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. Springer, Dordrecht.

Capítulo

2 Zonas de Estudio

ZONAS DE ESTUDIO

2.1 DESCRIPTIVA Y CARACTERIZACIÓN DE LAS ÁREAS DE ESTUDIO

Las zonas de estudio de la presente tesis pertenecen al ámbito de la Antártida Marítima, esto es, de la región biogeográfica de la costa oeste de la Península Antártica hasta 72º y los archipiélagos South Shetland, South Orkney y South Sandwich. La Antártida Marítima es la región más accesible y la más habitable de la Antártida siendo caracterizada por un clima más suave que en el resto del continente (Thomas et al. 2008). El clima de la Antártida Marítima se caracteriza por temperaturas veraniegas ligeramente por encima de cero grados y una cierta precipitación (400-500 mm) con una biodiversidad menor a la región sub-antártica pero mayor a la región continental (Huiskes et al. 2006). La existencia de estas condiciones extremas ha funcionado de manera natural como barrera ante la colonización de especies no nativas (Hughes et al. 2006). Sin embargo la zona está sufriendo uno de los mayores calentamientos del planeta (Vaughan et al. 2003, Turner et al. 2005, Turner et al. 2009). Asimismo debido a su proximidad con el cono sur americano, esta que conecta la Península con Patagonia a través del Mar de Hoces o paso de Drake (un estrecho de 1000 Km^2) siendo la vía de acceso más frecuente a la Antártida para la mayoría de programas nacionales, así como para la gran parte de la industria turística comercial (Enzenbacher 2007). De esta forma la región se muestra especialmente vulnerable ante invasiones biológicas, las cuales ya han tenido un profundo impacto en ambientes sub-antárticos con numerosas introducciones (Wiham et al. 2006, Convey et al. 2006).

Concretamente las investigaciones se desarrollan en distintos espacios las Islas Shetland del Sur y de las costas del noroeste de la Península Antártica. La ubicación de las zonas de estudio se muestra en la Figura 2.1, a su vez la Fig. 2.2 relaciona las zonas de estudio con las investigaciones realizadas en cada espacio.

2.1.1 El archipiélago de las Shetland del Sur

Frente a la región mas septentrional de la Península se encuentran las Islas Shetland del Sur, formadas por la Isla Smith, Low, Livingston, Snow, Decepción, Greenwich, Robert, Nelson, Rey Jorge, Elefantina e Isla Clarence (las mayores) así como multitud de islotes y archipiélagos asociados de los que destacar para este estudio el archipiélago Aitcho, la Isla Pingüino y la Isla Media Luna. Este conjunto islas a su vez contiene zonas costeras libres de hielo relativamente extensas que son frecuentemente la ubicación del primer destacamento de los programas nacionales en el continente antártico (en ocasiones el único), tales como Alemania, Argentina, Brasil, Bulgaria, China, Chile, Ecuador, España, Perú, Polonia, Reino Unido, Rusia y Uruguay (COMNAP 2012). Ya los primeros visitantes, foqueros y balleneros se extendieron por estas islas para explotarlas (Smith & Simpson 1987, Dibbern 2010) dejando múltiples rastros de su actividad comercial en forma de sitios o monumentos históricos (p.ej: H.S.M 21, 32, 34, 35, 36, 50, 52, 59, 71, 76, 83...) (ATS 2012a). Estas mismas zonas libres de hielo albergan hoy extensas comunidades de fauna y flora, siendo, junto con los restos históricos de actividades pasadas, de gran interés turístico en forma de sitios de visita regulados (p.ej: Punta Hannah, I. Media Luna, B. Yankee, B. Balleneros, I. Pingüino, I. Barrientos…) (ATS 2012b). No obstante algunas de las zonas libres de hielo contienen grandes valores naturales y científicos, por lo se encuentran protegidas para limitar el acceso y preservar los sitios dando lugar a una notable concentración de ASPAs (p.ej. 112, 125, 126, 132, 133, 140, 145, 149, 150, 171...) (ATS 2012c). En consecuencia, en estas islas se da aglutinamiento en unos pocos espacios libres de hielo con numerosas bases científicas, refugios y sitios históricos, áreas protegidas y lugares de visita del turismo antártico. No obstante, únicamente aparecen designadas en esta zona de confluencia de actividades dos Áreas Antárticas Especialmente Administradas (ASMAs Nº1 Bahía Almirantazgo y Nº4 Isla Decepción).

Isla Livingston. (62°37'S 60°27'O)**.** Esta isla, oficialmente descubierta por W. Smith, forma parte de los primeros enclaves en ser colonizados por los foqueros pioneros (Smith & Simpson 1987). Actualmente presenta dos bases científicas de verano en funcionamiento (Juan Carlos I (España) y Arwchowski (Bulgaria)) y al menos un campamento permanente (el Refugio Internacional Byers mantenido por España), dos áreas protegidas (ASPAs 126 Península y Byers 149 Cabo Shirreff, numerosos sitios arqueológicos y dos sitios turísticos con numerosos visitantes anuales (Isla Media Luna y Punta Hannah).

La Punta Hannah (ATS 2012b) es uno de los espacios más visitados y con mayores debates en cuanto a la conservación en las reuniones ATCM. Este espacio ha registrado un promedio entorno a 5.000 visitantes en los últimos años según los informes anuales de la asociación de tour operadores (IAATO 2011). Los ambientes costeros con suelos sueltos y la escasa vegetación inducen a considerar un bajo impacto por pisoteo. En cambio la exuberante megafauna y la interacción directa de los visitantes con esta en su recorrido alertan de posibles molestias a los animales. La pingüinera mixta de pingüino papúa (5.000 parejas aproximadamente) y de barbijo (unas 1.000 parejas) en la Punta es un ejemplo de colonia con una elevada presión humana de tipo turística que pudiera reflejar un impacto derivado de la mera presencia humana (ver capítulo 4.3).

La Península Byers (ASPA 126) (ATS 2012c) es el enclave fundamental del presente trabajo. Se trata de una de las mayores zonas libres de hielo especialmente protegidas con más de 80 Km^2 (ATCM 2011, Measure 4). La meteorología y climatología de la zona se caracteriza por su exposición al paso de Drake, con una temperatura media anual por debajo de 0º, fuertes vientos y hasta 800 mm de precipitación (Ellis-Evans 1996). La zona cuenta con una historia de cerca de 200 años de actividad humana intermitente. Los primeros pobladores fueron foqueros de distintas nacionalidades (Smith & Simpson 1987). Restos de su actividad han quedado en forma de lugares arqueológicos. A lo largo de la historia del ASPA numerosas expediciones científicas han contribuido al conocimiento del lugar dejando un legado de investigaciones. Por ello como parte de la presente tesis se ha realizado un trabajo de recopilación bibliográfica e integración de estudios realizados sobre los valores del espacio protegido (véase Benayas et al. 2013; recogido en el apartado 2.2). Hoy en día es un ejemplo de ASPA marcadamente internacional con grandes retos de conservación. Dentro del ASPA el campamento español en funcionamiento desde el año 2001 ha sido clave para el estudio de la evaluación y gestión de impactos derivados de la ocupación y el pisoteo. En 2011 fue reconvertido a Refugio Internacional Byers para su uso libre ordenado futuro como instalación para investigar en el ASPA. De tal forma el ciclo de vida de este campamento es objeto de seguimiento ambiental en el capítulo 4.5. Las playas sur entorno al campamento contienen extensas praderas de vegetación libres de toda actividad humana salvo la investigación (regulada por el Plan de Gestión del ASPA con, entre otros aspectos, limitación del número de permisos simultáneos otorgados, lo que es evaluado en la red de seguimiento de visitas a ASPAs del capítulo 4.4.) desde la declaración del ASPA en 1996. Por ello estas comunidades han sido tomadas como punto de referencia para desarrollar el artículo 4.1 sobre la protección de comunidades vegetales terrestres sensibles. Por otro lado la colonia de pingüino papúa en Punta Devils (cerca de 5.000 parejas) se encuentra libre de presencia humana respecto a otras colonias de la zona. De esta forma la pingüinera de Devils es un punto control en el estudio de los efectos de la presencia humana en colonias de aves (capítulo 4.3).

Isla Decepción. (62°58'S 60°39'O). Es una de origen volcánico, próxima a Isla Livingston, que desde principios de siglo XX ha sido un importante enclave estratégico en el que confluyen numerosas naciones e intereses (Dibbern 2010), siendo finalmente designada como el ASMA Nº4 en 2002. La isla contiene dos bases antárticas, dos sitios de interés históricos, cinco lugares de visita del turismo, dos áreas protegidas y una red áreas de trabajo de investigadores en torno a la geología y la biología del lugar. La naturaleza de vulcanismo activo de la isla y su forma de herradura con el cráter principal inundado y por tanto accesible por vía marítima propicia su gran singularidad generando contrapuestos los intereses científicos, turísticos y conservacionistas (ATCM 2012a).

En cuanto a la presencia científica, el ASMA incluye dos estaciones funcionando actualmente así como campamentos temporales y presencia de buques científicos de distintos programas nacionales. La base argentina Decepción y la base española Gabriel de Castilla, ambas en la mitad oeste de la isla funcionan como estaciones de verano alojando entre ambas unos setenta ocupantes sumando investigadores y personal de apoyo. Uno de los espacios más estudiados por científicos españoles en los últimos 20 años es la pinguinera de Collado Vapor con una población estable estimada en más de 20.000 parejas de pingüino barbijo (Naveen et al. 2012). Así este espacio forma igualmente parte de la red de estudio de colonias de pingüino en la presente tesis como el referente de presencia científica en la que la interacción con la colonia es potencialmente más intensa que la presencia turística (capítulo 4.3).

En cuanto a la presencia turística, la isla contiene uno de los lugares más visitados en toda la Antártida: la Bahía Balleneros, recibe hasta 18.000 visitas anuales declaradas según los informes anuales de la asociación de tour operadores (IAATO 2011). En la bahía se encuentran los restos de una factoría ballenera y la antigua base B del Reino Unido (abandonada tras las erupciones de los años setenta) (Dibbern et al. 2012), designado hoy como uno de los conjuntos históricos más llamativos y singulares del continente, el HSM 71 (ATS 2012a). Unido a las aguas termales derivadas del vulcanismo de la isla que invitan a los baños turísticos conducen a la numerosa presencia anual en la Bahía Balleneros y distintas actividades recreativas que ponen en riesgo los valores del sitio (Roura 2012). En este espacio se ha detectado recientemente una especie no nativa cuyo origen podría ser atribuido a la presencia humana (Smith & Richardson 2010). Además de este sitio la isla alberga otros sitios de interés turístico en su mitad este con una presencia considerable, como la Bahía Teléfono que da acceso a la vista de los cráteres de las ultimas erupciones en 1970, la Bahía Péndulo con sus fuentes termales y la base chilena destruida por las erupciones (HSM 77) y la pingüinera de Morro Baily con una extraordinaria población de pingüino barbijo (más de 70.000 parejas) en aparente retroceso (Naveen et al. 2012).

Finalmente el ASMA recoge dos áreas especialmente protegidas (ATS 2012c) dentro de la red de seguimiento del capítulo 4.4. El ASPA 145 está formado por 2 subsitios marinos en la bahía interior de la isla (Puerto Foster) y protege los ambientes bénticos formados sobre las erupciones (ATCM 2005). A su vez el ASPA 140 está formada por numerosos subsitios terrestres dispersos por la isla en los que se protegen raras comunidades biológicas asociadas a los suelos geotermales, típicamente dominadas por musgos (ATCM 2012b). Estos musgos son especialmente sensibles al pisoteo como se verá en el capítulo 6 y se encuentran asimismo en lugares de interés científico con presencia de investigadores debido a las anomalías térmicas existentes. De esta forma surge un conflicto en esto ambientes, por ejemplo, entre intereses conservacionistas de la biología y los requerimientos científicos para el estudio de la geología y física del lugar. Es por ello necesaria una gestión especial en la que se marquen las pautas de uso en lugares de confluencia de valores. Igualmente el ASPA trata de preservar ambientes aislados de la erosión o de bioinvasiones, como pueden ser lagos costeros e interiores, algunos de ellos próximos a sitios de visita. En este caso el conflicto incorpora a los intereses turísticos frente a los de conservación. Asimismo la confluencia de actividades supone una potencial fuente de introducción de especies siendo una amenaza real para el estado natural de la isla. Por todo ello la gestión de espacio se sitúa en un nivel máximo de complejidad dentro del panorama antártico (Downie 2007), siendo explorado en el capítulo 4.6.

2.1.2 El Noroeste de la Península Antártica

Frente a las islas Shetland del Sur y separadas con estas por el estrecho de Bransfield, se encuentran las costas del noroeste de la Península Antártica, las cuales de norte a sur son denominadas Costa Davis (63-64º), Costa Danco (aprox. 64-65º) y Costa Graham (aprox. 66-67º). También se incluye aquí los islotes y archipiélagos asociados así como las cercanas islas Adelaida, Anvers, Bravant y D'Urville. Son la región más septentrional del continente antártico físico como tal, y albergan pequeños espacios libres de hielo adyacentes a la intermitente plataforma de hielo sobre el eje central de la Península Antártica, la cual localmente recibe distintos nombres (Detroit, Bruce y Avery Plateau respectivamente para las costas descritas). La región contiene bases dispersas, en menor concentración que las Islas Shetland del Sur pero aún frecuentes frente a otras regiones de la Antártida. Las bases presentes pertenecen a los programas nacionales de Argentina, Chile, Estados Unidos, Reino Unido y Ucrania (COMNAP 2012). Junto a estas aparecen sitios históricos como por ejemplo los HSM 26, 29, 45, 55, 56, 61, 62, 84… (ATS 2012a). A su vez aparecen distintas ASPAs repartidas por la Península e islas asociadas, por ejemplo: 117, 129, 134, 139… (ATS 2012c). Finalmente el noroeste de la Península Antártica congrega un alto número de sitios de visita, mayor incluso que aquellos de las islas Shetland del Sur, al respecto Lynch et al. (2010) recogen la distribución espacial del turismo por la Península Antártica a través de las rutas de los cruceros de la IAATO. Aquí podemos destacar algunos de los sitios más visitados con directrices de visita (p.ej: I. Cuverville, I. Petermann, Puerto Neko, Puerto Lockroy o Base Palmer) (ATS 2012b).

Caleta Cierva (64°09'S 60°57'O). Se trata de una pequeña zona libre de hielo en el norte de la Península Antártica (Costa de Danco) con un microclima favorable por su ubicación resguardada (Mataloni et al. 1998). El promontorio rocoso de la caleta Cierva junto con la bahía e islas constituye el ASPA 134 designado en 1985 (ATCM 2006). Este área protegida presenta entre otros valores unas extensas praderas de vegetación dominadas por musgos con algunas propiedades similares a la Península Byers en cuanto a encharcamiento y elevada biomasa y otras singulares asociadas al terreno pedregoso. La zona igualmente una de las estaciones de investigación más antiguas, la base argentina Primavera, antiguo refugio Capitan Corbett (Corte 1961). Esta base es doblemente singular, por un lado se encuentra inmersa en un ASPA lo cual es extremadamente inusual y conlleva una gestión particular dentro del plan de gestión del área (similar a un campamento en zona protegida). Así la gestión de impactos de la investigación en torno a la base puede equipararse a la del campamento Byers (en tanto a su ubicación en un ASPA). Por otro lado destacar la construcción de pasarelas a consecuencia del terreno accidentado en el entorno de la base como estrategia que evita el pisoteo directo de las comunidades vegetales. Igualmente señalar la introducción accidental de una planta no nativa en la caleta durante experimentos de germinación en los años 50 (Corte 1961). El estudio de este caso particular nos permite evaluar el riesgo de establecimiento y persistencia de especies no nativas en el continente y desarrollar protocolos de erradicación ante la amenaza de una bio-invasión en una zona protegida.

Los lugares de estudio considerados en esta tesis se completan con una serie de islotes situados en la zona de la Península Antártica: la islas **Ronge** (Costa de Danco) y **Avian** (ASPA 117), y los **Islotes Jalour** (Costa de Graham). Estas localizaciones se utilizaron para los estudios sobre niveles de estrés en colonias de pingüinos. Cada uno de estos espacios es descrito pormenorizadamente más adelante (capítulo 4.3).

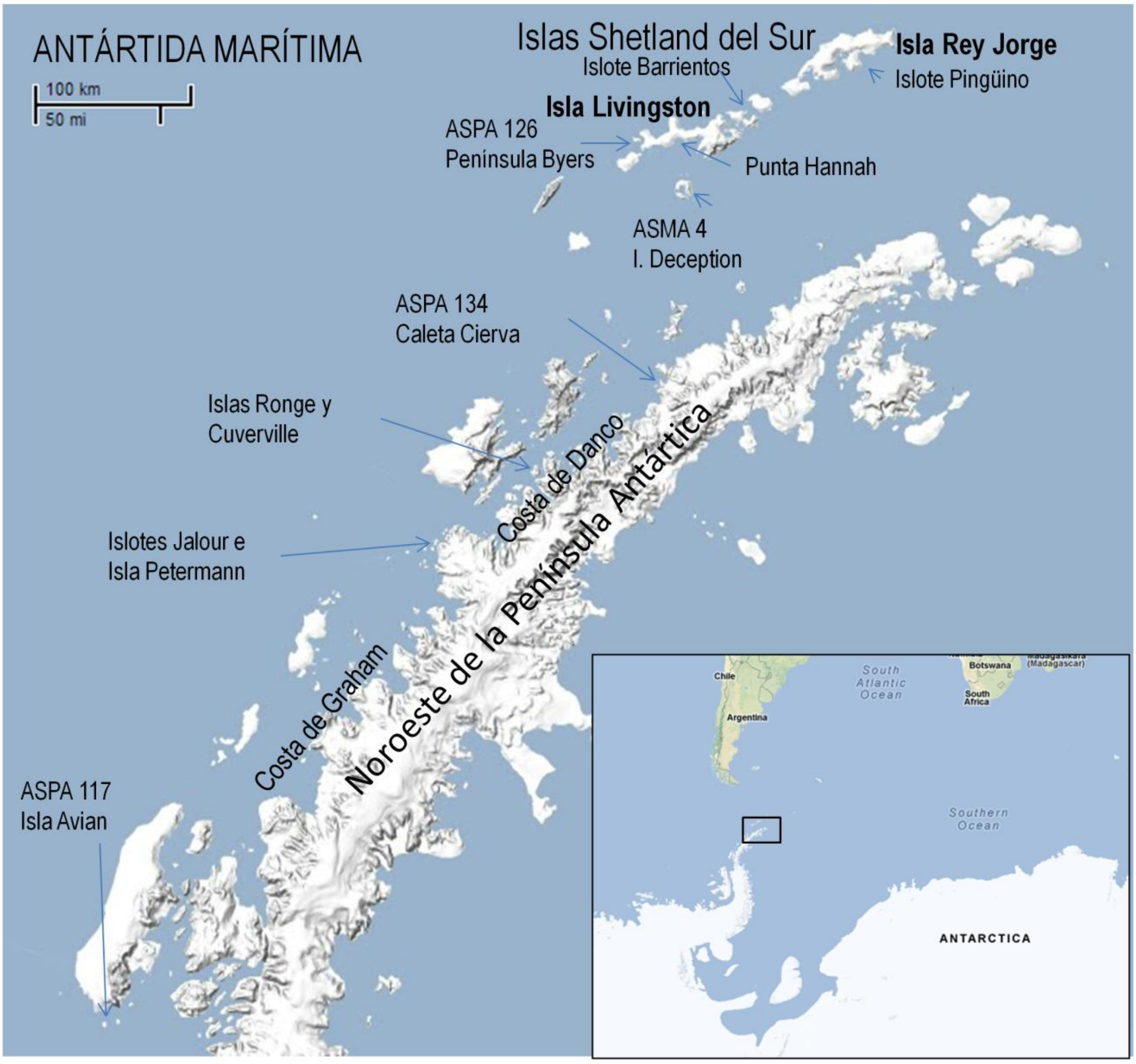

Fig 2.1. Ubicación de las zonas principales de estudio dentro de la Antártida Marítima. En el mapa se observan las dos grandes áreas de trabajo consideradas en la investigación: el archipiélago de las Islas Shetland del Sur y la zona noroeste de la Península Antártica. Fuente: Modificado de Google Maps - Google 2012.

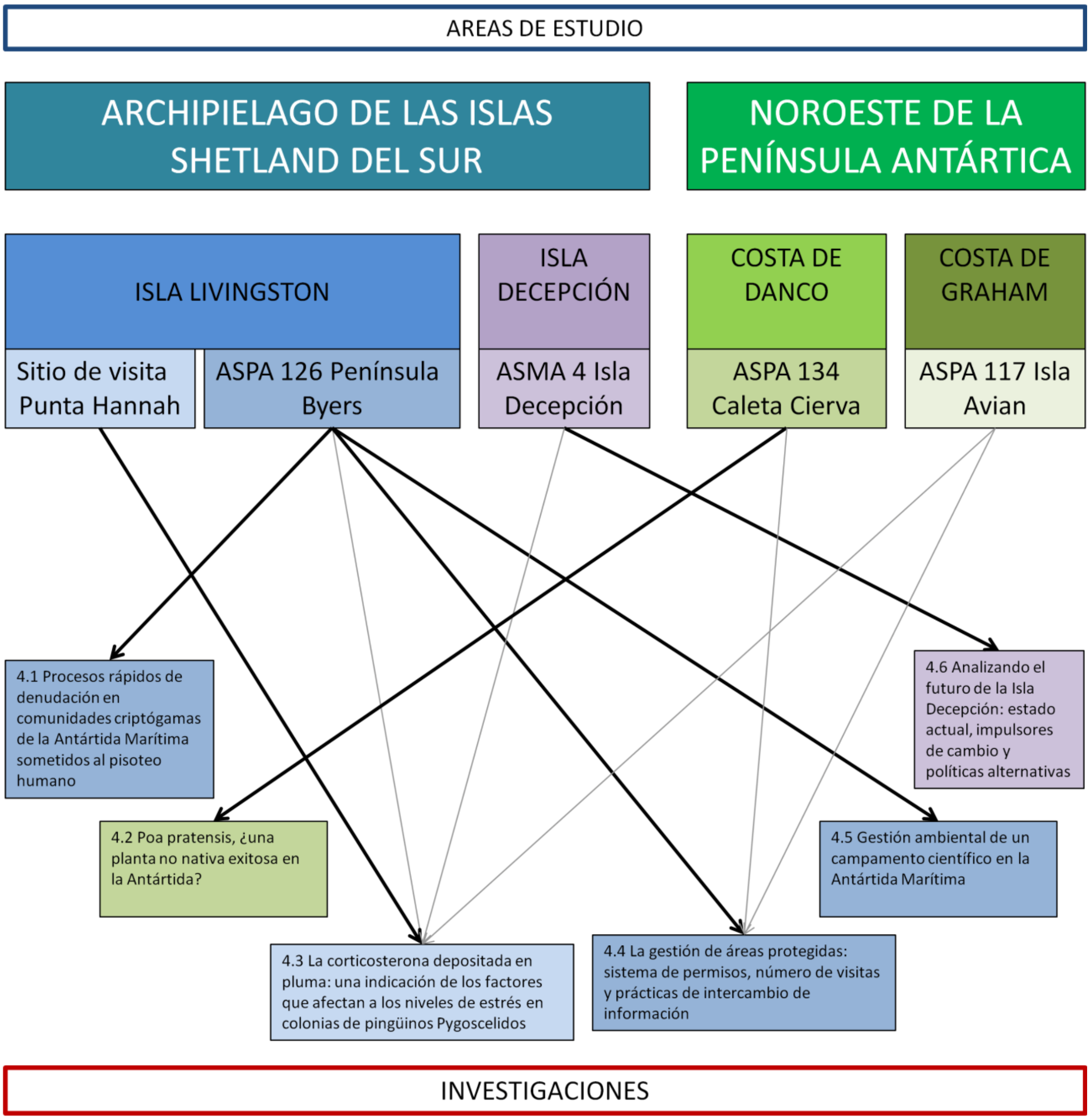

Fig. 2.2. Esquema de las zonas principales de estudio dentro de la Antártida Marítima disgregadas por ámbito geográfico. Se proponen dos niveles de trabajo dentro de esta área biogeográfica: la región (archipiélago de las Islas Shetland del Sur *versus* noroeste de la Península Antártica) y la localización concreta en la que se desarrolló la investigación (isla o zona costera). Cada área de estudio se relaciona con las distintas investigaciones desarrolladas. Esta relación puede ser primaria o exclusiva (flecha resaltada en negrita), secundaria o parcial (flecha normal), o inexistente (sin conexión). Las investigaciones aparecen coloreadas en relación a su área de estudio principal.

REFERENCIAS BIBIOGRÁFICAS DEL APARTADO

- ATS (Antarctic Treaty Secretariat) 2012a. List of Historic Sites and Monuments approved by the ATCM (2012). http://www.ats.aq/documents/ATCM35/WW/atcm35_ww003_e.pdf
- ATS (Antarctic Treaty Secretariat) 2012b. Antarctic Treaty. Tourism. Site Guidelines for visitors. http://www.ats.aq/e/ats_other_siteguidelines.htm
- ATS (Antarctic Treaty Secretariat) 2012c. List and status of ASPA and ASMA management plans. http://www.ats.aq/documents/ATCM35/WW/atcm35_ww004_e.pdf
- ATCM (Antarctic Treaty Consultative Meeting). 2005. Management Plan for Antarctic Specially Protected Area No. 145 Port Foster, Deception Island, South Shetland Islands. Measure 3, Report of the Twenty-eight Antarctic Treaty Consultative Meeting. Estocolmo, Suecia. http://www.ats.aq/documents/recatt/Att284_e.pdf
- ATCM (Antarctic Treaty Consultative Meeting). 2006. Management Plan for Antarctic Specially Protected Area No. 134 Cierva Point, Danco Coast. Measure 1, Report of the Twenty-nine Antarctic Treaty Consultative Meeting. Buenos Edimburgo, Escocia. http://www.ats.aq/documents/recatt/Att332_e.pdf
- ATCM (Antarctic Treaty Consultative Meeting). 2011. Management Plan for Antarctic Specially Protected Area No. 126 Byers Peninsula, Livingston Island, South Shetland Islands. Measure 4, Report of the Thirty-fourth Antarctic Treaty Consultative Meeting. Buenos Aires, Argentina. http://www.nsf.gov/od/opp/antarct/aca/nsf01151/703 aca2_spa126.pdf.
- ATCM (Antarctic Treaty Consultative Meeting). 2012a. Management Plan for Antarctic Specially Protected Area No. 140 Parts of Deception Island, South Shetland Islands. Measure 8, Report of the Thirty-five Antarctic Treaty Consultative Meeting. Hobart, Australia. http://www.ats.aq/documents/recatt/Att511_e.pdf
- ATCM (Antarctic Treaty Consultative Meeting). 2012b. Management Package for Antarctic Specially Managed Area No. 4 Deception Island, South Shetland Islands. Measure 10, Report of the Thirty-five Antarctic Treaty Consultative Meeting. Hobart, Australia. http://www.ats.aq/documents/recatt/Att512_e.pdf
- Benayas J, Pertierra RL. Tejedo P. Bermudez O. Lara F. Hughes KA. & Quesada A. (2013). A review of scientific research trends within ASPA 126 Byers Peninsula, South Shetland Islands, Antarctica. Antarctic Science, doi:10.1017/S0954102012001058.
- Convey P. (2006). Antarctic Climate change and its influence on terrestrial ecosystems, in Bergstrom, P. Convey and A.H.L. Huiskes (eds.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. Springer, Dordrecht.
- COMNAP (Council of Managers of Antarctic National Programs). 2012. List of Antarctic facilities. https://www.comnap.aq/Members/Shared%20Documents/Antarctic_Facilities_List_1April2012.xls
- Corte A (1961) La primera fanerógama adventicia hallada en el continente antártico. Contribución del Instituto Antártico Argentino 62, 14 pp.
- Dibbern S.J. 2010. Fur seals, whales and tourists: a commercial history of Deception Island, Antarctica. Polar Record 46 (238): 210–221 (2010)
- Downie, R. (2007). Deception Island. In: Riffenburgh, B. (ed.) Encyclopedia of the Antarctic. New York, Routledge, 327-328.
- Enzenbacher, D. (2007). Antarctic Tourism Policy-making: Current Challenges and Future Prospects. In: TRIGGS, G. & RIDDELL, A. (eds.). Antarctica: legal and environmental challenges for the future. London: The British Institute of International and Comparative Law. pp. 155-189.
- Hughes, K.A, Fretwell p. Rae j. Holmes k. & Fleming A. 2011 Untouched Antarctica: mapping a finite and diminishing environmental resource. Antarctic Science, 23, 537-548.
- Huiskes, A.H.L., Convey, P., Bergstrom, D.M. (2006) Antarctica as a global indicator: An introduction. In: Bergstrom, D.M., Convey, P., Huiskes, A.H.L. (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. 1-13

- Hughes, K.A, Ott, S., Bölter, M., Convey, P. (2006) Colonization processes. In: Bergstrom, D.M., Convey, P., Huiskes, A.H.L. (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. 35-55
- Ellis-Evans, J.C. 1996. Biological and chemical features of lakes and streams. In: López-Martínez, J., Thomson, M. R. A., Thomson, J.W. (eds.) Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series Sheet 5-A, 20-22. British Antarctic Survey, Cambridge
- IAATO (International Association of Antarctic Tour-Operators) (2011). Overview of Antarctic Tourism: 2010-11 Season and Preliminary Estimates for the 2011-12 Season. Information Paper 106, XXXIV Antarctic Treaty Consultative Meeting, Buenos Aires, Argentina, 20 June – 1 July, 2011.
- IAATO (International Association of Antarctic Tour Operators). 2012. Guidelines for visitors to the Antarctic. http://iaato.org/es/visitor-guidelines. Visitado por última vez en Diciembre 2012.
- Lynch, H.J., Crosbie, K., Fagan, W.F. & Naveen, R., 2010. Spatial patterns of tour ship traffic in the Antarctic Peninsula region. Antarctic Science, 22(2), pp. 123-130
- Mataloni G, Tesolín G, Tell G (1998) Characterization of a small eutrophic Antarctic lake (Otero Lake, Cierva Point) on the basis of algal assemblages and water chemistry. Polar Biol 19: 107-114
- Molenaar, E.J. (2005). Sea-borne tourism in Antarctica: avenues for further intergovernmental regulation. Internat. J. Marine Coastal Law, 20: 247-295.
- Naveen, R., Lynch, H. J., Forrest, S., Mueller, T., & Polito, M. (2012). First direct, site-wide penguin survey at Deception Island, Antarctica, suggests significant declines in breeding chinstrap penguins. Polar Biology, 35(12), 1879-1888
- Roura, R. M. (2012). Being there: examining the behaviour of Antarctic tourists through their blogs. Polar Research.
- Smith, R.I.L. & Simpson, H.W. 1987. Early nineteenth century sealer refuges on Livingston Island, South Shetland Islands. British Antarctic Bulletin, 74, 49-72.
- Smith, R.I.L. & Richardson, M., (2011) Fuegian plants in Antarctica: natural or anthropogenically assisted immigrants? Biological Invasions, 13(1), pp. 1-5.
- Thomas, D. N., Fogg, G. E., Convey, P., Fritsen, C. H., Gili, J. M, Gradinger, R., Laybourn-Parry, J., Reid, K. & Walton, D. W. H. (2008). The Biology of Polar Regions (2nd Edition). Biology of Habitats Series. Oxford: Oxford University Press.
- Turner, J, Colwell, S.R. MARSHALL, G.J. Lachlan-Cope, T.A. Carleton, A.M. Jones, P.D. Lagun, V. Reid P.A. & Iagovkina S. (2005) Antarctic climate change during the last 50 years. Int. J. Climatol. 25: 279–294 (2005)
- Turner, J., Bindschadler, R. A., Convey, P., Di Prisco, G., Fahrbach, E., Gutt, J., Hodgson, D. A., Mayewski, P. A. & Summerhayes, C. P. (Eds.) (2009). Antarctic Climate Change and the Environment. Cambridge: Scientific Committee on Antarctic Research.
- Vaughan, D.G., Marshall, G.L., Connolley, W.L., Parkinson, C., Mulvaney, R., Hodgson, D.A., King, J.C., Pudsey, C.J. & Turner, J. 2003. Recent rapid regional climate warming on the Antarctic Peninsula. Climatic Change, 60, 243-274.
- Whiman J. Copson G. & Chapius J.L. (2006) Sub-antarctic terrestrial conservation and management. In: Bergstrom, D.M., Convey, P., Huiskes, A.H.L. (ed.) Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator. Springer, Dordrecht.

2.2 Revisión de las tendencias en la investigaciones desarrolladas en el ASPA 126, Península Byers, Islas Shetland del Sur, Antártida

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Resumen La Península Byers, Isla Livingston, es uno de los primeros lugares de la Antártida designados especialmente para la conservación ambiental y la protección de las investigaciones. La investigación en la Península Byers ha sido predominantemente internacional, con al menos 88 publicaciones indexadas (con el 93% de ellas publicadas en los últimos 20 años) de 209 autores afiliados a 110 instituciones de 22 países, todos ellos firmantes del Tratado Antártico. Los estudios paleontológicos conforman el 20% de los artículos publicados. Asimismo la variedad de cuerpos de agua dulce convierte a la Península Byers en un sitio de referencia para estudios limnológicos (generando el 24 % de las publicaciones). La existencia de numerosos afloramientos y formas periglaciares son de gran relevancia para estudios geológicos, estratigráficos y geomorfológicos (con un 29 % agregado de publicaciones). La biodiversidad terrestre es extraordinariamente alta en grupos como líquenes, musgos e invertebrados (15 % de los artículos). Solamente un 5 % de los artículos aluden a actividades humanas, incluyendo estudios arqueológicos y monitoreo de impactos ambientales. Finalmente la glaciología, meteorología y climatología representa un 7% de las publicaciones. Este trabajo destaca la internacionalidad y multidisciplinaridad de las investigaciones en la Península Byers para promover la cooperación internacional y proporcionar información relevante para la gestión ambiental y la conservación.

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A review of scientific research trends within ASPA 126 Byers Peninsula, South Shetland Islands, Antarctica

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Abstract: Byers Peninsula, Livingston Island, was one of the first sites in Antarctica designated for environmental conservation and scientific protection. Research on Byers Peninsula has been predominantly international, with 88 indexed publications (93% of them published during last 20 years) from 209 authors affiliated to 110 institutions from 22 nations, all of which are signatories to the Antarctic Treaty. Palaeontological research represented 20% of the published articles. The variety of freshwater bodies within the area has made Byers Peninsula a reference site for limnological studies (24% of papers). The site also contains numerous outcrops and periglacial features relevant to geology, stratigraphy and geomorphology (29%). Terrestrial biodiversity is extraordinarily high for lichens, bryophytes and invertebrates (15% of articles). Only 5% of the publications concern research on human activities, including both archaeology and impact monitoring. Glaciology, meteorology and climatology studies represent only 7% of papers. This work highlights the international and multi-disciplinary nature of science conducted on Byers Peninsula in order to promote international cooperation and to provide information relevant for environmental management and conservation.

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Key words: climate, geology, limnology, Livingston Island, palaeontology, protected areas, terrestrial biodiversity

Introduction

Byers Peninsula (62°34'S, 61°13'W) is a protected area of 84.7 km^2 in the west of Livingston Island, South Shetland Islands. Climate in the region is characterized by average summer temperatures slightly above freezing point. Precipitation is relatively high with 800 mm per year, mostly as rain in summer (Ellis-Evans 1996), and winds are moderate compared to other locations (Serrano 2003). As one of the largest areas of ice-free ground in the Antarctic Peninsula (Richard *et al*. 1994), it contains a remarkable variety of geological formations and ecosystems available for research.

The abundance of Antarctic fur seals (*Arctocephalus gazella* Peters) in this area attracted sealers in the early 19th century (Lewis Smith & Simpson 1987). However, the profitability of this activity was quickly reduced by systematic and uncontrolled hunting, and sealers soon left the area. In 1966, part of the Peninsula was designated as the Specially Protected Area (SPA) No. 10 by Recommendation IV-10 of the Antarctic Treaty Consultative Meeting (ATCM). The main aim was to conserve the biological values of the area, which included a high diversity of plant and animal life within a relatively small area. Designation as an SPA was changed in 1975 through Recommendation VIII-2, which redesignated the area as Site of Special Scientific Interest No. 6 (Recommendation VIII-4). The new designation protected three sites on the Peninsula where fossils provided evidence of the former link between other elements of Gondwana and Antarctica. The SSSI was subsequently extended through Recommendation XVI-5 (1991) to include boundaries similar to those of the original SPA, and protecting the scientific use of the biological and archaeological features of outstanding importance found in the Peninsula, in addition to the geological values previously cited. The protection status of the area changed again with its designation as an Antarctic Specially Protected Area (ASPA) No. 126 for the full site adopted in 2001 by Decision 1 (2002). The management plan was adopted by Measure 1 (2002) and recently revised by Measure 4 (2011). ASPA category may be applied both to terrestrial and marine areas to protect outstanding environmental, scientific, historic, aesthetic or wilderness values, any combination of those values, or ongoing or planned scientific research (Protocol on Environmental Protection to the Antarctic Treaty, Annex V, Article 3). As a result of this on-going protected status, human presence has been limited in the past 46 years to the scientific activity which may have reduced direct human impact in the area and kept it free of human influence relative to other ice-free areas in the vicinity (e.g. Deception Island or Fildes Peninsula, King George Island). During the International Polar Year, Byers Peninsula was defined as an International Reference Site for Research on terrestrial, limnetic and coastal ecosystems (Quesada *et al*. 2009).

The majority of ASPAs within the Antarctic Treaty area are small (with over 55% having an area of less than 5 km^2) and many protect only a single or limited number of values (Hughes & Convey 2010). ASPA 126 Byers Peninsula does not fit this mould. Unusually for a predominantly ice-free terrestrial ASPA, it is of a much larger scale and contains one of the most diverse ranges of values considered to be worthy of protection within the ASPA network. A challenge to environmental managers is to ensure that Byers Peninsula is protected in a way that considers and facilitates conservation of all of the values within the area. Mainly, this is undertaken through the Byers Peninsula ASPA management plan, which has the United Kingdom, Chile and recently Spain as proponent Parties. The management plan describes the values to be protected as: i) the exceptional diversity of terrestrial flora and fauna, ii) the numerous lakes, freshwater pools and streams, iii) the invertebrate fauna, iv) the abundant cyanobacterial mats, v) the diverse breeding avifauna, vi) the lake sediments for use in palaeoenvironmental research, vii) the well preserved sub-fossil whale bones, and viii) the exposed Jurassic and Cretaceous sedimentary and fossiliferous strata.

The present study aims to i) serve as a compendium of Byers science as a reference for future research, ii) analyse the diversity of investigations undertaken and the links between researchers, and iii) to identify key aspects for practical conservation of the site. We reviewed all available scientific literature relating to this site, conducted a bibliometric study of the scientific output to identify international research cooperation between the Antarctic Treaty parties then attempted to identify the emerging issues for practical environmental management and conservation at this site.

Material and methods

To fullfil these objectives an initial consultation was made of the bibliographic database Thomson's Scientific Citation Index (SCI). SCI is a widely accepted international citation system of more than 4000 peer-reviewed scientific and technical journals. Similar analyses to the present work have been made for Antartic science papers by Dastidar (2007). All published papers that included science on or about Byers were included in this review. The list was filtered to determine who were directly related with active research in Byers Peninsula. From the original list we eliminated all those papers with no research directly conducted in Byers Peninsula, such as those that indirectly cited Byers publications, for instance, by comparison of data from elsewhere with Byers research findings. In addition, relevant documents from other sources were included in this review in order to summarize current knowledge of Byers Peninsula. We used different tools for their detection, such as the *Cold Regions Bibliography Project* (www.coldregions.org), and several databases included by Antarctic national programmes on their own websites. References in each selected work were reviewed to detect other studies developed on Byers Peninsula. Finally, some distinguished experts were asked to review and complete the list of identified publications.

Next, a bibliometric analysis was performed on those publications included in the indexed journals of SCI. It is important to recognize that several relevant works for Byers Peninsula may have published in journals not included in SCI. Eight thematic areas were defined based on the main research conducted by the scientific field expeditions. These were: i) Glaciology, Climate and Meteorology, ii) Geology and Stratigraphy, iii) Geomorphology and Soils, iv) Palaeontology, v) Terrestrial biodiversity, vi) Limnology and Microbiology, and viii) the Human Dimension. Each article was allocated to one of the eight categories. Articles within this special issue have not been included in this analysis, although they may be considered a valuable reference for future research within Byers Peninsula. Changes in the level of scientific outputs were plotted by thematic area, and results were compared with article production across all of Antarctica over the same period. Techniques to determine the extent of collaboration between international researchers (Cross *et al*. 2002) were used to analyse scientific articles with joint authorship within SCI. The collaboration networks between i) researchers, ii) institutions, and iii) nationalities were derived.

Science summaries from the published papers

Research on glaciology, climate and meteorology

Everett (1971) proposed at least three glacial events for Livingston Island, which had a decreasing intensity. The specific climate history and deglaciation chronology of Byers Peninsula have been described by several authors using lake sediments analysis. John & Sugden (1971) proposed that Byers Peninsula was largely free of permanent ice by 9700 yr BP, whereas Björck *et al*. (1991a, 1991c, 1993, 1996), Hjort *et al*. (1992) and Björck & Zale (1996), suggested a more recent general deglaciation of central Byers Peninsula of around 4000–5000 yr BP. But Björck *et al*. (1991b) pointed out the problems of ^{14}C dating in Antarctica due to the reservoir effect and the need for a careful evaluation of the proposed radiocarbon dates. Other researchers have used ice rafted detritus from raised beach ridges on Byers Peninsula to analyse this issue (Hall & Perry 2004). This material was used by Hall (2010) to determine the nature and timing of glacial and climate fluctuations in Antarctica relative to those in the rest of the Southern Hemisphere. Data showed a complex pattern characterized by ice transgressions over the area at ~6000–7000 and ~400 yr BP, which may have been linked to glacial advance. Other works have focused on earlier series of the Quaternary system. Hall (2003) reviewed ice fluctuations during the late Pleistocene glaciation in the South Shetland Islands, including data obtained on Byers Peninsula. Recent studies suggest the deglaciation of some capes and peninsulas at around 9500 yr BP, a regional advance between 6000 and 4500 yr BP (Hall 2009, Michalchuck *et al*. 2009) and a last small advance of ice domes and ice occupying the cirques during the Little Ice Age (López-Martínez *et al*. 2012). Growth rings in Cretaceous and Tertiary wood from different sampling sites, including Byers Peninsula, were also used by Francis (1986) to analyse the climate in those periods.

Current meteorology at this site was described by Bañón (2004) and Bañón *et al*. (2006), who proposed the existence of a microclimate. Before these publications, descriptions of Byers Peninsula climate were generally vague (i.e. Ellis Evans 1996, Serrano 2003), or were very specific studies such as those conducted by Hall (1992a, 1992b, 1993a, 1993b), who analysed the relationship of various rock surface temperatures to local climatic conditions and the annual number of air freeze-thaw cycles in summer. Rochera *et al*. (2010) pointed out that inter-annual variation in the meteorological conditions at this site could be significant, acting as a triggering factor for some limnological processes. The latest contribution by Bañón *et al*. (2013), proposed the use of regional weather data for landscape studies within the maritime Antarctica on the basis of their research on Byers Peninsula.

Geology and stratigraphy

To the best of our knowledge, the first reconnaissance geological survey of Byers Peninsula was carried out by Hobbs (1968), who described agglomerates near Start Point and andesite lavas with interbedded sediments on the northern shores of New Plymouth. Hobbs attributed the rocks of this location to the Oligocene, probably because these agglomeratic rocks were petrographically similar to some from Point Hennequin, King George Island (Thomson 1992). The discovery of ammonites (*Spitceras*) belonging to the upper Titonian to Neocomian by González-Ferrán *et al*. (1970) on the coast of President Beaches eventually proved that parts, at least, were Early Cretaceous in age. Dalziel *et al*. (1970) also demonstrated the presence of Mesozoic rocks through the analysis of the ammonite fauna in sediments. Valenzuela & Hervé (1972) divided the Byers Peninsula into two areas. A "younger unit", composed mostly of agglomerates, overlies the "older unit" which is a fossiliferous sedimentary sequence, grading laterally from west to east, from marine to continental facies. These authors also produced the first 1:20 000 geological map of Byers Peninsula and described some patterned ground shapes. This proposal was extended by Pankhurst *et al*. (1979), who suggest that the unfossiliferous "younger unit" described by Valenzuela & Hervé (1972) is in part a time correlative of the upper (non-marine) facies of the "older unit". Lava flows and intrusions in the main non-marine outcrop are of Lower Cretaceous age, and igneous activity on Byers Peninsula concluded with dolerite plug and sill formation in Upper Cretaceous times. Pankhurst *et al*. (1979) reported K–Ar ages within the range 126–75 Ma from igneous rocks sampled on Byers Peninsula and provided a second geological sketch map. This geochronology was supported by further discoveries of Berriasian and Valanginian ammonite faunas at many localities throughout western and north-east Byers Peninsula (e.g. Hernández & Azcárate 1971, Covacevich 1976, Smellie *et al*. 1980, Askin 1983). Gracanin (1983) suggested that certain strata of Byers Peninsula were much older (Oxfordian) than previously reported (143 ± 5 Ma). At that time, Hansom (1979) obtained a radiocarbon age of between 2100 and 2400 yr BP for skeletal material from the 10 m high beach ridge at South Beaches, whereas the lowest beach deposits were dated at 300 yr BP (John & Sugden 1971, Sugden & John 1973).

Smellie *et al*. (1980) studied the geology of this site and assign the Byers Peninsula succession to a single major unit, the Byers Formation, which they divided into four members: Mudstone, Mixed Marine, Agglomerate, and Volcanic (Thomson 1992, Machado *et al*. 2005a). Lower Cretaceous rocks at Byers Peninsula were examined by Watts *et al*. (1984), Grunow (1993), and Poblete *et al*. (2011), showing uncertainties in the exact age of the main event of remagnetization, which could have been acquired during the Cretaceous Normal Chron. Crame *et al*. (1993) reviewed the previous stratigraphical work on Byers Peninsula and elevated Byers Peninsula to group status, dividing the strata previously assigned to the Mudstone and Mixed Marine members into four formations: Anchorage, Devils Point, President Beaches, and Chester Cone (Machado *et al*. 2005a). Arche *et al*. (1994) analysed the internal deformation processes affecting the Mixed Marine member of the Byers Formation, whereas Calvet *et al*. (1994) dated ash layers in several glaciers on Livingston Island and used the studies of lacustrine sediments of Byers Peninsula to conclude that the lowest layers may correspond to eruptions which occurred at the beginning of the 19th century. Hodgson *et al*. (1998) analysed lake sediment cores from Midge Lake for volcanic tephra, identifying five horizons. Four of these consisted of sodic basaltic to basaltic-andesitic glasses, and the fifth was a single acidic tephra, located on the top surface, at 2–3 cm. These volcanic materials derived from the Quaternary Deception Island volcano. Hathway (1997) proposed that the Upper Jurassic-Lower Cretaceous rocks of the Byers Group record the expansion of Gondwana-margin continental-arc facies into a marine intra-arc basin, and described in detail the Cerro Negro Formation, which appears to form part of an Early Cretaceous episode of arc-perpendicular extension. Arche *et al*. (1997) completed the study on the continental platform sediments in the Anchorage Formation, describing a wave-dominated outer shelf evolving towards an inner shelf with shoreface bars. These deposits were previously interpreted by Pirrie & Crame (1995) as deep marine sediments deposited at 1000 or more metres below sea level. González-Casado *et al*. (1997) established the main characteristics of fracturation in several outcrops around the central part of the Bransfield Basin, including most of the Byers Peninsula. Based on the facial study of a carbonate volcanic sequence, Cabaleri *et al*. (1997) proposed a shallow lacustrine environment subjected to an arid climate with seasonal rainfall and the presence of considerable organic matter at Byers Peninsula. Zheng *et al*. (1995, 1998a, 1998b) published several papers in Chinese journals summarizing the geology, volcanology and petrology of Livingston Island, although these studies provided few new insights into the geology of the Byers Peninsula.

Hathway & Lomas (1998) revised and extended the proposed scheme by Smellie *et al*. (1980) and Crame *et al*. (1993) completing the description that now is accepted for this area, which states that the bedrock of this location is composed of Upper Jurassic to Lower Cretaceous marine sedimentary, volcanic and volcaniclastic rocks, intruded by igneous bodies. Byers Peninsula forms part of a Mesozoic-Cenozoic magmatic arc complex which is exposed throughout the whole of the Antarctic Peninsula region. The idea of a lacustrine environment was reintroduced by Pimpirev & Vangelov (1999), who studied eight types of lithofacies to propose a series of delta palaeoenvironments which could be interpreted as an example of ancient subaqueous segment of deep-water mouth bar type delta system. Kiessling *et al*. (1999) revised the regional stratigraphy using data from co-occurring radiolarians and ammonites in Upper Jurassic sequences of the Antarctic Peninsula. Depositional processes on the President Beaches Formation and implications for slope apron depositional models were analysed by Lomas (1999). Oteiza (1999) went into the analysis of the Cerro Negro Formation obtaining a K–Ar age of 78 ± 5 Ma on a basaltic plug, whereas Yoo & Choe (2000) studied the sandstones of the Lower Cretaceous President Beaches Formation to infer the lithology and tectonic settings of this area. Demant *et al*. (2004) and Machado *et al*. (2005a) summarized and extended previous studies about the geochronology of the igneous rocks of Byers Peninsula. Machado *et al*. (2005b) analysed the isotope data and trace element concentrations for volcanic and plutonic rocks from the South Shetland Arc, including some samples from Byers Peninsula. Geochronology and palaeontological content of the Cerro Negro Formation were summarized by Parica *et al*. (2007). The tectonic and morpho-structural evolution of this site was described in detail by Alfaro *et al*. (2010). These authors analysed more than 1200 lineaments, and 359 fault planes from 16 sites, both in sedimentary and intrusive igneous rocks, with a length varying between 31 and 1555 m. Statistical analysis of lineaments and mesoscopic fractures showed a NW–SE maximum trend, with two NE–SW and ENE–WSW secondary maximums. Finally, Toro *et al*. (2013) reviewed the chronostratigraphy of the sedimentary record of Limnopolar Lake on Byers Peninsula, updating the available knowledge.

Geomorphology and soils

Thomson (1992) pointed out that Byers Peninsula is one of the most important areas of the South Shetland Islands from a geomorphological point of view. John & Sugden (1971) studied at length the Holocene beach succession and other geomorphic issues, describing a landscape dominated by a series of marine erosional platforms the highest of which, together with some upstanding volcanic residuals, forms the central part of the peninsula. Rock glaciers and patterned ground at around 10 m a.s.l. exists on Byers Peninsula (Arayá & Hervé 1972a, 1972b). Fluvial and periglacial processes are dominant presently, and there are few glacial landforms (López-Martínez *et al*. 1996a). The presence of moraines, one of the most common glacial formations, has been suggested as scarce and only three residual glaciers remain on Ray Promontory, covering less than 0.5 km^2 in total (Martínez de Pisón *et al*. 1996a). A detailed description of periglacial processes and landforms in the South Shetland Islands, including Byers Peninsula area, was recently published by López-Martínez *et al*. (2012).

Glaciology on Byers Peninsula has been studied by other authors, such as Orheim (1971) and Curl (1980). The former developed a mass balance programme on the small ice cap terminating on Byers Peninsula, on the western side of the island, and the latter reviewed the glacial history for this location. Hall (1994) analysed the role of snow cover on the spatial distribution of sorted stripes. More recently, Cuchí *et al*. (2004) described the physicochemical properties of various waters in a permafrost area of Byers Peninsula, and Fassnacht *et al*. (2010) studied the effect of aeolian deposition on the surface roughness of melting snow. Byers Peninsula was recently included in the CALM (Circumpolar Active Layer Monitoring) programme, locating a new CALM-S site near the south-west shore of the Limnopolar Lake (De Pablo *et al*. 2010, Vieira *et al*. 2010). This research aims to study and monitor the temporal evolution of the maximum active layer depth in different places and climates where permafrost exists. A complete analysis of the interannual variability of the active layer of this site was recently presented by

De Pablo *et al*. (2013). The knowledge about this area was extended by Fassnacht & Toro (2013), who expanded their previous studies and produced a map of the snow cover and snow depth across the Limnopolar Lake watershed.

Different geodetic and topographic surveys have been carried out by several research groups (SGE *et al*. 1993, Hernández-Cifuentes 1994), but the most detailed geomorphological map of Byers Peninsula was produced by López-Martínez *et al*. (1995, 1996a). These authors produced a map that included an explanatory text (Thomson & López-Martínez 1996) with chapters on topography (Hernández-Cifuentes *et al*. 1996), geomorphology (López-Martínez *et al*. 1996b), glacial features (Martínez de Pisón *et al*. 1996a), periglacial and nival landforms and deposits (Serrano *et al*. 1996), fluvial and lacustrine landforms and deposits (Ellis-Evans 1996, López-Martínez *et al*. 1996c), emergent and submerged marine landforms and deposits (Arche *et al*. 1996), upper Holocene tephrochronology (Björck & Zale 1996), palaeoclimate (Björck *et al*. 1996) and geomorphological evolution (Martínez de Pisón *et al*. 1996b). The humid maritime climate of the area, with snow and ice melting in summer, favours the development of an important drainage network (Birnie & Gordon 1980, López-Martínez *et al*. 1996c). Also the existence of 110 lakes and pools large enough to be mapped at 1:25 000 scale and occupying 1.5% of the area of the Peninsula is remarkable (López-Martínez *et al*. 1996c).

Lithosols are dominant on Byers Peninsula, with permafrost widespread below an active layer of 30–70 cm depth (Thom 1978, Ellis-Evans 1996, Serrano *et al*. 1996), although Cryosols and Leptosols are also present (Navas *et al*. 2005). A 10–20 cm deep layer of organic matter is present beneath some of the moss and grass communities, without deep accumulations of peat (Bonner & Lewis Smith 1985). Cryogenic processes, including the mechanical disintegration of bedrock, play a key role in soil development, but lixiviation and other chemical weathering processes were also involved in soil evolution although limited in extent due to the restriction of water circulation in the summer months (Navas *et al*. 2006, 2008). An initial study on Byers' soils was presented by Henríquez (1994). Ellis-Evans (1996) located some ornithogenic soils in the Devils Point vicinity and on a number of knolls along President Beaches. Navas *et al*. (2005) carried out a preliminary survey on the content of radionuclides in soils of Byers Peninsula, detecting certain variability related to mineralogy derived from parent materials, as well as with cryogenic and soil processes affecting the depth distribution of the granulometric fractions and the organic matter. Navas *et al*. (2008) also analysed the soil characteristics in mudstones and volcanic rocks in Byers Peninsula, observing that the elemental composition was closely related to the mineralogy of parent materials. The spatial distribution of soils from the northern part of Byers Peninsula was recently described by Moura *et al*. (2012). Their work proposed twenty different soil units, including Fluvisols, Regosols, Leptosols and Cryosols (according to the World Reference Base for Soil Resources), which correspond mostly to Fluvents, Orthents/Psamments, Inceptsols and Gelisols, respectively, according to the Soil Taxonomy. However, more information about the depth and spatial distribution of permafrost is necessary for a more conclusive classification of Cryosols or Gelisols.

Palaeontology

In Byers Peninsula, outcrops of sedimentary rocks are small and widely scattered but have provided much palaeontological information. The high value of this area has been highlighted by many authors e.g. Hernández & Azcárte (1971), Smellie *et al*. (1980), Crame (1984, 1995), Crame *et al*. (1993), Crame & Kelly (1995), Hathway & Lomas (1998). Following these studies, this area was found to have one of the most complete records of the Jurassic-Early Cretaceous period in the northern part of the Pacific flank of the magmatic arc complex, being a key succession for the study of marine molluscan faunas and non-marine floras. The exposed Jurassic and Cretaceous sedimentary and fossiliferous strata on Byers Peninsula also have an outstanding scientific value for study of the former link between Antarctica and other southern continents. Particularly fruitful has been the Cerro Negro Formation from where important plant megafossils, corresponding to the Lower Cretaceous age, have been found. Some general works initiated the palaeofloristic knowledge of this rich site (Hernández & Azcárate 1971, Torres *et al*. 1982, Césari *et al*. 1999), while more recent ones have centred on single finds or on palaeoecological interpretations. Byers Peninsula has led to the description of diverse, previously unknown, gymnosperms (Césari *et al*. 1998, Falcon-Lang & Cantrill 2001), ferns (Césari 2006, Vera 2007, 2009, 2010, 2012), and even bryophytes (Vera 2011). Simultaneously, the data obtained have allowed reconstructions of the South Shetlands Early Cretaceous palaeovegetation (Falcon-Lang & Cantrill 2002a, 2002b), and are relevant for the knowledge of the Mesozoic changes of vegetation in Antarctica (Orlando 1968, Cantrill & Poole 2005).

Complementary information has been obtained from palynological studies based on fossil palynomorphs, including spores, pollen, and fossil microplankton (dinoflagellate cysts). From these sources new data are available, and have allowed environmental reconstructions and established floristic links with other parts of Gondwana. Palaeopalinology studies from Byers Peninsula have not only generated data on the Cerro Negro Formation Aptian age (Hathway *et al*. 1999), but also the larger and possibly more interesting Late Jurassic–Early Cretaceous interval (Askin 1981, 1983, Duane 1994, 1996, 1997).

Limnology and microbiology

Byers Peninsula includes a high number of water bodies and can be considered one of the most useful sites for limnology in the Peninsula region. However, these non-marine aquatic ecosystems were not investigated until the late 1980s. The importance of environmental variables for species composition and abundance of periphytic diatoms was assessed by Hansson & Håkansson (1992) using data from 21 lakes, including some on Byers Peninsula. But the first local and purely limnological publications were contributed by Davey (1993a, 1993b), describing the dynamics of some streams and ponds from Byers Peninsula for the first time, and by Jones *et al*. (1993) who correlated the water chemistry with diatom diversity in freshwaters ecosystems of Byers Peninsula. A multidisciplinary expedition in 1990-1991 allowed the preparation of a general description of freshwater ecosystems by Ellis-Evans (1996). In 2001 the Limnopolar Programme started with a multidisciplinary perspective, based on the ecology of freshwater ecosystems from Byers Peninsula. Over a 10 year period, the different ecosystems were described in detail and numerous experimental methods provided new and interesting results, predominantly concerning limnology. Examples of these results can be found in Toro *et al*. (2007), which includes the most detailed information on numerous water bodies in the peninsula, and Lyons *et al*. (2013), who described the geochemistry of several streams from Byers Peninsula. During the development of the project different organizational levels were explored, from viral and bacterioplankton communities (López-Bueno *et al*. 2009, Schiaffino *et al*. 2011, Villaescusa *et al*. 2013) to ecological dynamics (Camacho 2006, Villaescusa *et al*. 2010, Pla-Rabes *et al*. 2013). A large variety of new aquatic species were found, as well as a huge viral and ciliate diversity (Petz *et al*. 2007, López-Bueno *et al*. 2009), some new invertebrate species including oligochaetes (Rodriguez & Rico 2008), and an increased number of diatom species (Van de Vijver *et al*. 2009, 2011, Zidarova *et al*. 2010, 2012, Kopalová & Van de Vijver 2013). Agius *et al*. (2009) also confirmed that the winged Antarctic midge *Parochlus steinenii* (Gerke) was not a recent introduction to the Antarctic Peninsula region, and new diagnostic DNA techniques were developed by Bissett *et al*. (2005) with samples from Limnopolar Lake. These works culminated with the International Polar Year, with Byers Peninsula subject to an international and multidisciplinary research season in which more than 30 scientists participated with the aim of designating Byers Peninsula as an International Site of Reference for ecological studies. This successful project provided the tools and information for carrying out integration studies, such as the one from Velázquez *et al*. (2013) in which vegetation, geochemistry and limnology in the watershed were considered together. In recent years, all the knowledge regarding the structure, functioning and biotic interactions in Byers Peninsula aquatic ecosystems have been widely described in several informative works and book chapters (Camacho & Fernández-Valiente 2005, Petz *et al*. 2005, Quesada *et al*. 2006, Toro *et al*. 2008, Quesada *et al*. 2008, Vincent *et al*. 2008, Rochera *et al*. 2011, Pearce & Laybourn-Parry 2012, Vincent & Quesada 2012, Camacho *et al*. in press).

Several nematophagous fungi have been described through the analysis of soil samples from Byers Peninsula in areas occupied by *Deschampsia antarctica* Desv., *Colobanthus quitensis* (Kunth) Bartl. and the moss *Sanionia uncinata* (Hedw.) Loeske (Gray & Smith 1984, Bonner & Lewis Smith 1985). Microbial biodiversity in water bodies was analysed by López-Bueno *et al*. (2009), describing the largest viral genetic diversity found in any Antarctic lakes. The association between the ericoid mycorrhizal fungus *Rhizoscyphus ericae* and the Antarctic leafy liverwort *Cephaloziella varians* was studied by Upson *et al*. (2007) using material from Byers Peninsula, among other sites across a 1875 km transect through sub- and maritime Antarctica. These authors also analysed root-fungal associations of *Colobanthus quitensis* and *Deschampsia antarctica* in another 1480 km latitudinal transect from South Georgia (54°S, 36°W) through to the Léonie Islands on the western Antarctic Peninsula (67°S, 68°W), again working with samples from Byers. Rhizobia strains in cryospheric habitats were analysed by Nakai *et al*. (2013). In recent years, microbial mats have received significant attention from the scientific community. They constitute the dominant biomass in ice-free surfaces on Byers Peninsula. Numerous projects have been initiated to investigate several issues related to these multi-layered sheet of micro-organisms, including their dynamics (Velázquez *et al*. 2011), physiology and composition (Fernández-Valiente *et al*. 2007, Rochera *et al*. 2013a, 2013b) as well as their cold adaptation (Velázquez *et al*. 2011, Kleinteich *et al*. 2012).

Terrestrial biodiversity

As a major area within the maritime Antarctica that is ice-free in the summer and characterized by a relatively favourable climate, Byers Peninsula has both varied vegetation and a diverse flora. Nevertheless, the number of published studies based on the botany of this area is quite limited. The vegetation of Byers Peninsula is mainly known through the work of Lindsay (1971b), who used observations at this location to characterize typical vegetation types for the whole South Shetlands archipelago. Most of the 20 cryptogamic and three phanerogamic or bryo-phanerogamic assemblages described by Lindsay (1971b) occur on Byers Peninsula, although no detailed information about their distribution is available. Nevertheless, there is substantial floristic knowledge of different plant groups from the Peninsula. The two Antarctic native phanerogams are present there (Lindsay 1971b) and their distribution and reproductive capacity have now been assessed (Vera 2013). Particularly comprehensive data have been collected on the bryophytes of Byers. The monumental work of Ochyra *et al*. (2008) includes references for 42 species of mosses, 17 of which are only known from within the relatively well-studied Livingston Island. Pertierra *et al*. (2013b) provided two additional records of mosses, one of them a novelty for the island, the other previously unknown in the South Shetlands. Moreover, Bednarek-Ochyra *et al*. (2000) compiled the records of liverworts and reported six species from Byers Peninsula. Information on the lichen flora of Byers Peninsula is found in several publications (e.g. Lindsay 1969a, 1969b, 1971a, 1973, Lewis Smith & Øvstedal 1991, Sancho *et al*. 1992, Matzer *et al*. 1994, Wirtz *et al*. 2003), but at least 56 lichen species are certainly known from Byers Peninsula (ATCM 2011). Casanovas *et al*. (2012) used data from a wide variety of Antarctic sites, including Byers Peninsula, to develop a multi-scale analysis of moss and lichens richness patterns on the Antarctic Peninsula. Finally, when considering the non-marine microalgae, the information on the terrestrial diatom flora of Byers is particularly outstanding (Van de Vijver & Zidarova 2011, Zidarova *et al*. 2010, Kopalová & Van de Vijver 2013). Lewis Smith (1985) also reported the occurrence of several driftwood specimens on Byers Peninsula, predominantly of southern South American provenance, which could be serving as possible agents of biological immigration and colonization.

Richard *et al*. (1994) reported the first detailed study of the terrestrial invertebrate fauna of the Byers Peninsula using samples from a wide range of terrestrial and freshwater habitats, although earlier reports described the insects on Byers Peninsula (e.g. Greene *et al*. 1967, Bonner & Lewis Smith 1985, Edwards & Usher 1985). Fourteen micro-arthropod taxa (10 Acari and four Collembola) and two chironomid midges (Diptera) were recorded by Richard *et al*. (1994). Convey *et al*. (1996) revised this, adding a new species of springtail. A molecular clock approach to dating the presence of the Antarctic chironomid midges was employed by Allegrucci *et al*. (2006). This study included material from Byers Peninsula, and proposed the separation of those populations in the South Shetland Islands from other in Patagonia and sub-Antarctic South Georgia between 49 and 68.5 million years BP, depending on the species. Tardigrade eggs recovered from Limnopolar Lake were used by Gibson *et al*. (2007) to assess post-glacial colonization and Holocene tardigrade dynamics on the Southern Continent. Results suggested a slow colonization from Antarctic sources rather than wind transport from extra-continental sites. Rodríguez & Rico (2008) described the new enchytraeid species *Lumbricillus healyae* from freshwater streams situated in Byers Peninsula. Nielsen *et al*. (2011) recorded 37 nematode taxa in soil samples from this site, and proposed that the location be considered a nematode biodiversity hotspot. Their results indicated that abiotic factors influence nematode communities with little evidence of biotic interactions. Allegrucci *et al*. (2012) used samples from Byers Peninsula to analyse the molecular relationships between three species of chironomid midges: *Belgica antarctica* Jacobs, *Belgica albipes* Séguy and *Eretmoptera murphyi* Schaeffer. More recently, Rico & Quesada (2013) analysed natural drift patterns of Chironomidae populations in freshwater habitats of maritime Antarctica, including data from within Byers Peninsula.

In the case of vertebrate fauna Byers Peninsula was extensively used for sealing in the first decades of 19th century. The sealing activity reduced the populations in the region enormously, to levels where seals were almost completely eradicated in some locations (Lewis Smith & Simpson 1987). Once the sealing activity declined marine mammals populations recovered to some degree. The breeding marine fauna in Byes Peninsula is dominated by elephant seals (*Mirounga leonina* L.) that can have a population of over 5000 individuals in 2011 which is two-fold higher than that found during the previous count in the 1960s (see Gil-Delgado 2013, and references therein). Other abundant mammals include leopard seals (*Hydrurga leptonyx* Blainville) and Antarctic fur seals (*Arctocephalus gazella* Peters). *Cryptosporidium* and *Giardia*, two ubiquitous protozoan parasites which infect a wide variety of hosts, were analysed in faecal samples from different species of Antarctic pinnipeds by Rengifo-Herrera *et al*. (2011). These parasites were absent from Byers Peninsula samples.

The ornithofauna in Byers Peninsula is emblematic for this region and has been investigated by Gil-Delgado *et al*. (2013) who provided a new census of the dominant species: Antarctic tern (*Sterna vittata* Gmelin) with a population of about 3700 individuals, kelp gull (*Larus dominicanus* Lichtenstein) with a population of about 1900 individuals, giant petrel (*Macronectes giganteus* Gmelin) with 2800 individuals, and the Antarctic skua (*Catharacta antarctica lonnbergi* Mathews) with less than 100 birds in the area. The largest penguin colony is of gentoos (*Pygoscelis papua* Forster) with about 2400 individuals. The chinstrap penguin (*Pygoscelis antarcticus* Forster) are also present but with only 50 pairs. Other studies were performed on penguins, investigating the effects of tourism on the animals and using the Byers Peninsula colony as the control which experienced almost no human impact (Barbosa *et al*. 2013). Also, the presence of pathogenic bacteria has been investigated in the Byers Peninsula bird communities (Abad *et al*. 2013). Emslie *et al*. (2011) studied an abandoned penguin colony on Byers Peninsula and used radiocarbon dating to obtain an age of 285–480 yr BP for the last occupation of the site, although the authors estimated that penguin occupation lagged behind deglaciation by over 2000 years. Recently, Emslie *et al*. (2013) have applied a stable isotope analysis to ancient and modern gentoo penguin egg membranes to assess the krill surplus hypothesis in Antarctica, and obtained results that support this theory.

Human dimension

Byers Peninsula was one of the first sites in Antarctica to be occupied, and consequently has experienced almost two centuries of intermittent human presence. Thus, science is not the only discipline studied on Byers; sealers' refuges and artefacts from the early 19th century have also been a source of extensive archaeological research (Lewis Smith & Simpson 1987, Zarankin & Senatore 2005, Pearson *et al*. 2008, 2010, Stehberg 2008, Stehberg *et al*. 2009). More than twenty refuges are documented in the area; some of them remain relatively well preserved with visible stone walls and small quantities of waste, such as glass bottles fragments. Early inhabitants of the South Shetland Islands have also left marine debris. Wood from sunken sailing boats has been found on Byers Peninsula and large quantities of debris can be found in the President and Robbery beaches as well as in coastal lakes (Harris 2001, Pertierra unpublished results). Also, pelagic plastics from different marine sources have been found on Byers Peninsula (Gregory & Ryan 1997, ATCM 2011). The origins of this debris is not fully known; however, the type and quantity of waste recorded suggested that little can be linked with existing or abandoned field camps.

Recently, the research and logistic activities conducted in the former Spanish camp, now the Byers international camp, have been subject to retrospective impact assessments (Pertierra *et al*. 2013a). Byers International camp site has served as a case study for soil and vegetation trampling monitoring at remote scientific field camps in ASPAs. As a result a range of trampling strategies have been published (Tejedo *et al*. 2005, 2009, in press, Pertierra *et al*. 2013b). Doran & Vincent (2012) included Byers Peninsula in a list of protected subglacial aquatic environments, describing a

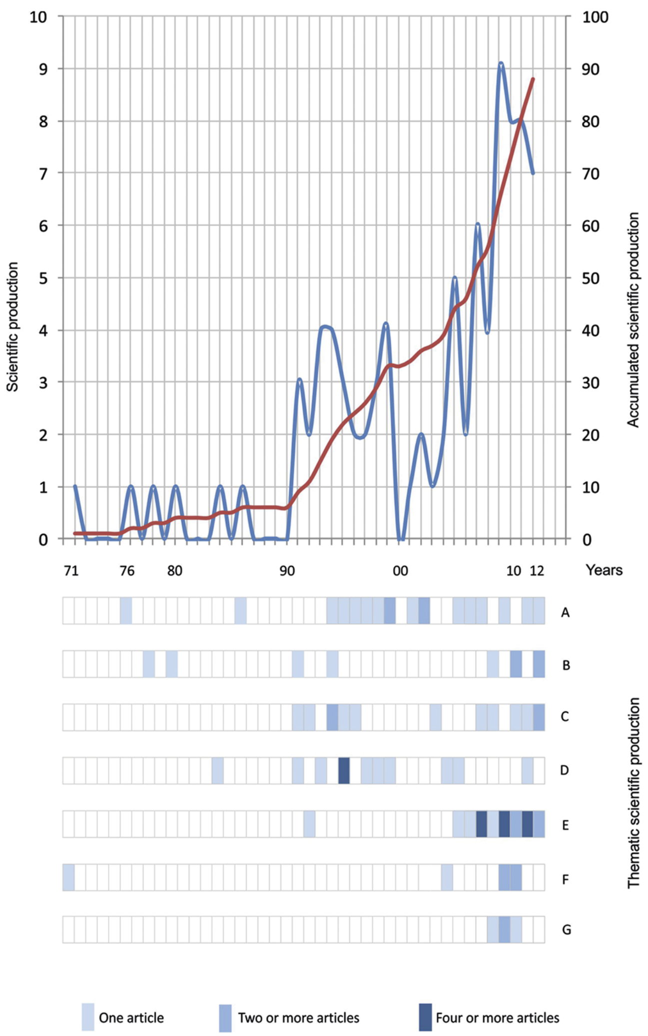

Fig. 1. Scientific paper publication over time resulting from research on Byers Peninsula (1971–2012). A: Palaeontology, B: Geomorphology and Soil, C: Terrestrial Diversity, D: Geology and Stratigraphy, E: Limnology and Microbiology, F: Glaciology, Meteorology and Climate, and G: Human Dimension. Each bar represents a one year period. The number of publications per year is represented in three categories indicated by three colour intensities. This research incorporated only publications that appeared in Journal Citation Reports.

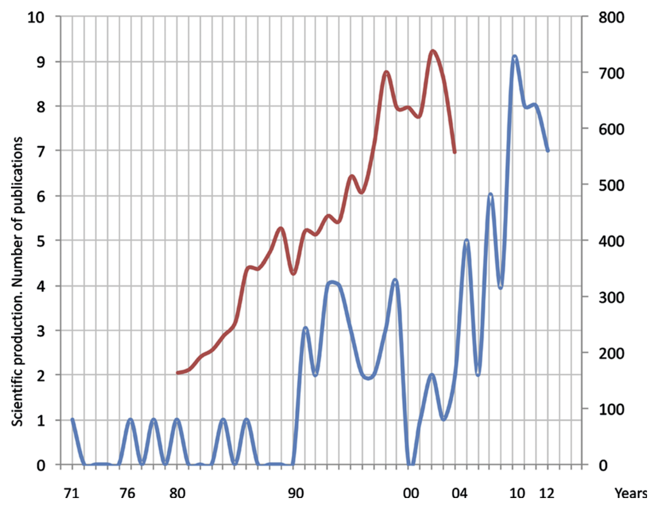

Fig. 2. Comparison of the level of scientific paper publication over time in resulting from research in Byers Peninsula and Antarctica as a whole. The red line shows the number of scientific paper produced each year concerning the whole of Antarctic science (Dastidar 2007) (right axis). In comparison the blue line indicated the number of publications produce each year on science performed within Byers Peninsula (left axis).

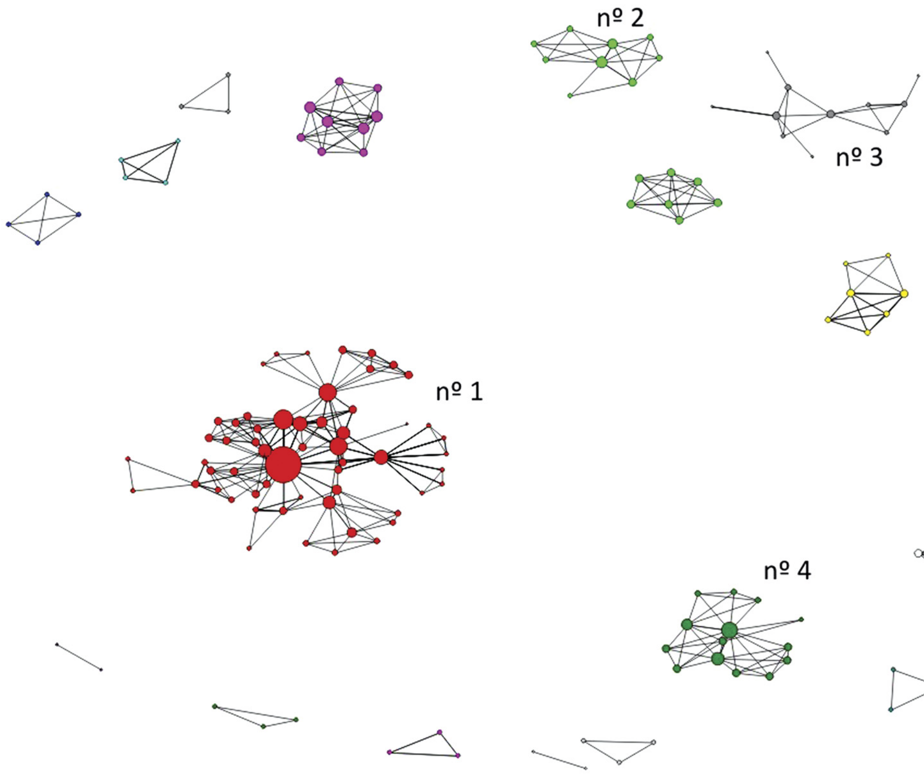

Fig. 3. Co-authorship social network. This figure attempts to show the level of interaction between researchers. Every node represents a single researcher, the size of the nodes indicates the number of publications by each author (degree). The lines show the relationships between the authors in the different publications (links).

Code of Conduct for the exploration of these environments formulated by a Scientific Committee on Antarctic Research Action Group. Finally the site has been used to assess the influence of field camps on the occurrence of organic pollutants in Antarctic soils and vegetation (Cabrerizo *et al*. 2012).

Fig. 4. Institutions participating in the publication of scientific research on Byers Peninsula. The eleven nations that engage in international collaborations are represented by researchers from 61 institutions. Each node represents the institutions participating in the publications. The size of the dots depends on the number of publications and the lines represent the co-authorship between different institutions.

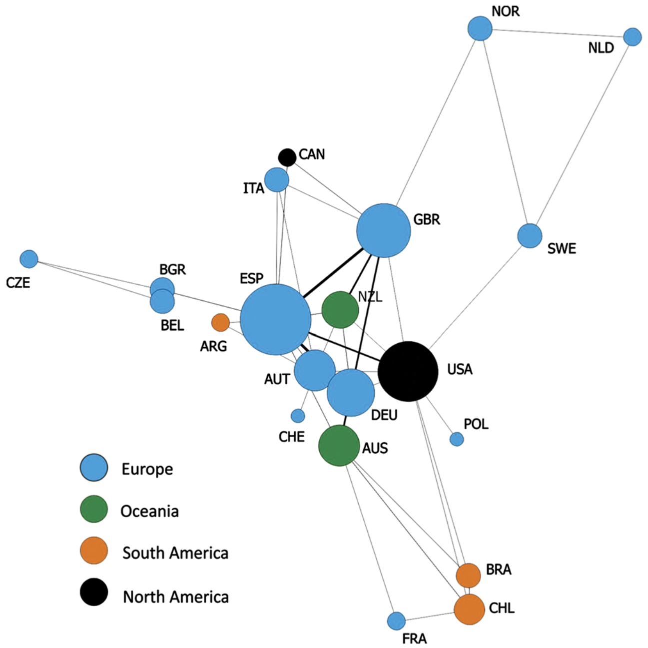

Fig. 5. Nations producing scientific publications based on research within Byers Peninsula. Each node represents the nationality of the institutions producing the scientific papers. The size of the nodes indicates the number of articles per nationality and the lines, the nationalities of the institutions sharing authorship of the articles.

Bibliometric analysis

We analysed scientific outputs by SCI from 1971 to early 2012. Around 93% of the articles have been published in the last 22 years (1990–2012) (Fig. 1). The curve of scientific productivity showed a positive trend, similar to the trend for Antarctica publications as a whole for the period 1980–2004 (Dastidar 2007) (Fig. 2).

The diversity of articles, classified by themes, was broad: Palaeontology (20%), Microbiology and Limnology(24%), Geology and Stratigraphy (19%), Terrestrial Biodiversity (15%), Geomorphology and Soil (10%), Human Dimension (5%) and Glaciology, Climate and Meteorology (7%).

More than 200 authors have contributed to scientific research from Byers Peninsula (Fig. 3). In total 24 research groups were found with a minimum of two related authors and of these, 12 groups have five or more related authors. The rest are small independent research teams. In contrast, four aggregations contain nine or more related authors and three or more publications. These four clusters incorporate 44% of all authors and 54% of publications and are seen as big independent research consortia. In the main group, at the centre of Fig. 3, 58 authors are clustered. These authors belong to 110 institutions that have created a diffuse research network (Fig. 4). The node in the centre (Universidad Autónoma de Madrid, Spain) has the highest values for social connectivity (eigenvector) and has relationships with 45 of the 109 other institutions analysed (13 of which are Spanish).

The 110 institutions belong to 22 nations, all of which are signatories to the Antarctic Treaty. Of these nations, 21 have joint publications with scientist from other nations (Fig. 5). The country with scientific publications but no international authorship is South Africa (Hall 1994). More than half of the publications are from three countries: Spain (28%), United Kingdom (18%) United States (9%). In this analysis, Spanish institutions have collaborated to the largest extent, with research links with institutes in eleven different countries (Argentina, Canada, Belgium, Bulgaria, Italy, Austria, New Zealand, Germany, United States, Australia and United Kingdom). A high level of international cooperation can be seen in Byers Peninsula research, with 66% of the articles co-authored by researchers from two or more institutions from two or more countries.

Discussion

Byers Peninsula research: a hotspot of scientific values

Research on Byers Peninsula is of great interest to scientist from a diverse range of scientific disciplines. Hathway & Lomas (1998) pointed out that the sedimentary and igneous outcrops constitute the best fossiliferous sequence for the Jurasic and Lower Cretaceous periods in the Pacific side of the Scotia Arc complex. These outcrops give highly valuable information for both geology and stratigraphy, and for the palaeontologic registry of marine molluscs and non-marine palaeobotany from these periods. Moreover, this area may have the most complete limnetic system in this region of the maritime Antarctic, with more than 60 lakes, freshwater pools and a dense network of temporary streams which are dependent upon seasonal snowmelt. The sediments within lake systems provide an essential archive for the study of the Holocene palaeo-environment in the Antarctic Peninsula. From a biodiversity point of view, Byers Peninsula is considered a hotspot for Antarctica, with numerous species of different biological groups.

Research into all of these values has, and will continue, to require the presence within the ASPA of scientists from a wide range of scientific disciplines, including ornithology, entomology, botany, limnology, microbiology, geomorphology, geology and conservation biology. More recently, the development of increasingly sophisticated metagenomic techniques, which can now be incorporated readily into field research, has brought scientists from a new range of molecular biological disciplines into Byers Peninsula (e.g. López-Bueno *et al.* 2009). Multidisciplinary research often yields scientific insights of greater impact and value than science that focuses on only one discipline. Therefore, the presence of so many values of scientific interest within one area makes Byers Peninsula of immense value for research (Quesada *et al*. 2009), particularly as Antarctica continues to change. Furthermore, the long history of research in the area also makes it of potential value for the study of climate change impacts on terrestrial and lacustrine habitats and across a range of biological groups.

Nonetheless, the research lines conducted in Byers Peninsula have varied considerably since the original designation of the site as an SPA in 1966. Often the number of publications in certain disciplines are focussed around specific time periods (Fig. 1). This can be explained by the development of specific projects, for instance the production of publications concerning limnological studies has been mostly associated with the Limnopolar expeditions from 2001–10. On the other hand, periods of multidisciplinary scientific production in Byers Peninsula can be partially related to special events, such the International Expedition during the 1990–91 season. However, the rate of scientific production has been relatively consistent in the cases of palaeontology and, to a lesser degree, in geomorphology. It is also important to highlight the recent development of other areas such biological conservation in more recent years. Finally, when we compared levels of publication resulting from Byers Peninsula research with publications concerning Antarctica as a whole, we found a strong correlation (Fig. 2). The similar patterns may also reflect the participation in international events within Antarctica, such as the International Polar Year (IPY) during the 2008–09 season.

The social network analysis revealed the existence of different research groups in the scientific history of Byers Peninsula (Fig. 3). Up to 24 consortia were found to be present in the past or still active in research in the area with four dominant associations. When we examine the instutitional network, we find a high level of relationship complexity (Fig. 4) involving institutes in 22 nations (Fig. 5). The proportion of Byers Peninsula publications co-written by contributors from different countries (66%) is much higher than that identified by Dastidar (2007) for all the scientific publications of Antarctica (34.42% in 2004). As shown by Bartneck & Hu (2010) higher levels of collaboration in multidisciplinary fields increased the scientific outputs associated from each investigation. This is especially relevant in Antarctica where every field activity, inevitably, has some environmental cost. Thus, it is crucial that all results obtained on Byers Peninsula be published to avoid repetition and reduce the possibility of unnecessary reiterative visits, since human presence will always represent an impact in this almost pristine region.

Environmental management of Byers Peninsula

The current Byers Peninsula ASPA management plan attempts to take into consideration the needs and interests of the numerous scientific disciplines working in the area, the overarching requirement to protect natural values of this site, and the requirements of each Party operating within the ASPA boundary. Specifically, the management plan aims to i) avoid degradation of, or substantial risk to, the values of the area by preventing unnecessary human disturbance, ii) allow scientific research on the terrestrial and lacustrine ecosystems, marine mammals, avifauna, coastal ecosystems and geology, iii) allow other scientific research within the area provided it is for compelling reasons which cannot be served elsewhere, iv) allow archaeological research and measures for artefact protection, while protecting historic artefacts present within this site from unnecessary destruction, disturbance, or removal, v) prevent or minimize the introduction to the area of alien plants, animals and microbes, vi) minimize the possibility of the introduction of pathogens which may cause disease in fauna within the ASPA, and vii) allow visits for management purposes in support of the aims of the management plan. A balance has been found that attempts to accommodate all of these aims, and the management plan details a range of conditions that must be met before permits should be granted for entry to the area. Many of the conditions (e.g. disposal of waste, sampling of materials, installation of equipment and structures) are common to other ASPA management plans. However, there have been some new initiatives that apply specifically to Byers Peninsula. In 2011, the management plan underwent a major revision and an international field camp was designated (62°34'35"S, 61°13'07"W), so that camping impacts are focused at one location, and two restricted zones were designated to protect the relatively pristine nature and scientific importance for microbiology of parts of the ASPA. In an attempt to preventing microbial or other contamination by human activity, those with permits to enter the restricted zones must wear sterile protective over-clothing, and to the maximum extent practicable, use only previously sterilized general field equipment and scientific equipment. In addition, camping and helicopter landings are not permitted.

ASPA 126 Byers Peninsula is unique within the Antarctic Protected Area System in being the only ASPA with three proponent Parties (out of the 71 ASPAs, 68 have a single proponent, and only two have two proponent Parties). To some degree, this may reflect international interest in the area and the willingness for Parties to engage in its protection. Nevertheless, better co-operation and communication between Parties and researchers is necessary for the continued protection of the values found within the area. Tourists are not permitted in the area, but inevitably long-term scientific research and environmental management activities have lead to some minor levels of impact, for example, by the creation of a path to an intensely studied lake, the presence of unmarked scientific apparatus of unknown origin and the presence of evidence of past field camps. Added to this, we still have no clear data on the level of introductions of non-native macro- and microbiota to the area, or information on the past use of stable or radioisotopes for scientific purposes. Both issues are generic across Antarctica.

Looking forward the overall protection of the area would be enhanced by: 1) more input into the environmental management of the ASPA by the various Parties who operate in the area, 2) better use of the existing Antarctic Treaty information exchange and reporting systems regarding the nature and location of activities undertaken in the area, 3) better on-going cooperation between Parties in the provision of logistical support for those working in the area, and 4) better interaction between scientists to prevent repetition of research that has already been undertaken. The high geodiversity and biodiversity and low levels of perturbation that characterize Byers Peninsula could in future lead to enhanced levels of research at this site. However, bearing in mind the need to protect and conserve the area, Antarctic Treaty Parties should only grant permits for scientific research within the Byers Peninsula ASPA *'provided it is for compelling reasons which cannot be served elsewhere'*, as specified in the area management plan. Furthermore, only studies whose impacts have been assessed as less than minor or transitory, should normally be permitted, as described in Annex I of the Protocol on Environmental Protection to the Antarctic Treaty.

Conclusions

The literature concerning Byers Peninsula, described in this paper, reflects the wide diversity of disciplines involved in research within this area over the past five decades. It is in the interests of all nations and scientists that Byers is conserved to the maximum degree possible, in order that this research may continue. The Antarctic Treaty System specifically encourages international cooperation between nations. Collaborations promote both enhanced productivity and permit coordination of different scientific and logistical activities, thereby avoiding duplicating efforts and minimizing unintentional impacts resulting from the scientific research. This work aimed to integrate the interdisciplinary scientific knowledge about Byers Peninsula in order to facilitate both future international cooperation and enhance the cooperative conservation of Byers Peninsula.

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Supplemental material

A supplemental table will be found at http://dx.doi.org/10.1017/S0954102012001058

References

Abad, F.X., Busquets, N., Sánchez, A., Ryan, P.G., Majó, N. & González-Solís, J. 2013. Bacterial infection in bird communities of Byers Peninsula. *Antarctic Science*, **25**, 10.1017/S0954[redacted].

Agius, J.T., Gibson, J.A.E., Rico, E. & Quesada, A. 2009. Paleolimnological evidence confirms that *Parochlus steinenii* (Gerke) is not a recent introduction to the Antarctic Peninsula region. *Chironomus*, **2**, 18–21.

Alfaro, P., López-Martínez, J., Maestro, A., Galindo-Zaldívar, J., Durán-Valsero, J.J. & Cuchi, J.A. 2010. Recent tectonic and morphostructural evolution of Byers Peninsula (Antarctica): insight into the development of the South Shetland Islands and Bransfield Basin. *Journal of Iberian Geology*, **36**, 21–37.

Allegrucci, G., Carchini, G., Tordisco, V., Convey, P. & Sbordoni, V. 2006. A molecular phylogeny of Antarctic chironomidae and its implications for biogeographical history. *Polar Biology*, **29**, 320–326.

Allegrucci, G., Carchini, G., Convey, P. & Sbodorni, V. 2012. Evolutionary geographic relationships among orthocladine chironomid midges from maritime Antarctic and sub-Antarctic islands. *Biological Journal of the Linnean Society*, **106**, 258–274.

Arayá, R. & Hervé, F. 1972a. Patterned gravel beaches in South Shetlands. *In* Adie, R.J., *ed. Antarctic geology and geophysics*. Oslo: International Union of Geological Science, 111–114.

Arayá, R. & Hervé, F. 1972b. Periglacial phenomena in the South Shetland Islands. *In* Adie, R.J., *ed. Antarctic geology and geophysics*. Oslo: International Union of Geological Science, 105–109.

Arche, A., Martínez de Pisón, E. & Serrano, E. 1994. Subaqueous sliding on Byers Peninsula. *In* Cacho, J. & Serrat, D., *eds. Actas del V Simposio Español de Estudios Antárticos*. Madrid: Comisión Interministerial de Ciencia y Tecnología, 170–171.

Arche, A., Martínez de Pisón, E. & Serrano, E. 1997. Sedimentos de plataforma continental dominada por el oleaje en la Formación Anchorage (Jurásico Superior), Península Byers, Isla Livingston. *Boletín de la Real Sociedad Española de Historia Natural, Sección Geológica*, **92**, 175–180.

Arche, A., López-Martínez, J., Serrano, E. & Martínez de Pisón, E. 1996. Marine landforms and deposits. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000*. Cambridge: British Antarctic Survey, 35–42.

Askin, R.A. 1981. Jurassic-Cretaceous palynology of Byers Peninsula, Livingston Island, Antarctica. *Antarctic Journal of the United States*, **16**(5), 11–13.

Askin, R. 1983. Tithonian (Uppermost Jurassic)-Barremian (Lower Cretaceus) spores, pollen and microplankton from the South Shetland Islands, Antarctica. *In* Oliver, R.L., James, P.R. & Jago, J.B., *eds. Antarctic earth science*. Cambridge: Cambridge University Press, 295–297.

ATCM (Antarctic Treaty Consultative Meeting). 2011. Management Plan for Antarctic Specially Protected Area No. 126 Byers Peninsula, Livingston Island, South Shetland Islands. *Measure 4, XXXIV Antarctic Treaty Consultative Meeting, Buenos Aires, June 2011*, 23 pp.

Bañón, M. 2004. *Introducción al clima de la Península Byers, Isla Livingston, Antártida. Comparación con la BAE Juan Carlos I*. MSc thesis. Instituto Universitario de Geografía, Universidad de Alicante, Spain, ??pp. [Unpublished].

Bañón, M., Justel, M.A. & Quesada, A. 2006. Análisis del topoclima y microclima de la isla Livingston, Antártida, en el marco del proyecto LIMNOPOLAR. *In XXIX Jornadas Científicas de la AME. Aplicaciones meteorológicas*. Madrid: Asociación Meteorológica Española.

Bañón, M., Justel, A., Velázquez, D. & Quesada, A. 2013. Regional weather survey in Byers Peninsula, Livingston Island, South Shetland Islands, Antarctica. *Antarctic Science*, **25**, 10.1017/S0954[redacted].

Barbosa, A., de Mas, E., Benzal, J., Diaz, J.I., Motas, M., Jerez, S., Pertierra, L., Benayas, J., Justel, A., Lauzurica, P., Garciapeña, F.J. & Serrano, T. 2013. Pollution and physiological variability in gentoo penguins at two rookeries with different levels of human visitation. *Antarctic Science*, **25**, 10.1017/S0954102012000739.

Bartneck, C. & Hu, J. 2010. The fruits of collaboration in a multidisciplinary field. *Scientometrics*, **85**, 41–52.

Bednarek-Ochyra, H., Váňa, J., Ochyra, R. & Smith, R.I.L. 2000. *The Liverwort Flora of Antarctica*. Cracow: Polish Academy of Sciences, 236 pp.

Birnie, R.V. & Gordon, J.E. 1980. Drainage systems associated with snow melt, South Shetland Islands, Antarctica. *Geografiska Annaler*, **62A**, 57–62.

Bissett, A., Gibson, J.A.E., Jarman, S.N., Swadling, K.M. & Cromer, L. 2005. Isolation, amplification, and identification of ancient copepod DNA from lake sediments. *Limnology and Oceanography*, **3**, 533–542.

Björck, S. & Zale, R. 1996. Late Holocene tephrochronology and palaeoclimate, based on lake sediment studies. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000*. Cambridge: British Antarctic Survey, 43–48.

Björck, S., Sandgren, P. & Zale, R. 1991c. Late Holocene tephrochronology of the northern Antarctic Peninsula. *Quaternary Research*, **36**, 322–328.

Björck, S., Hjort, C., Ingolfsson, O. & Skog, R. 1991b. Radiocarbon dates from the Antarctic Peninsula Region: problems and potential. *Quaternary Proceedings*, **1**, 55–65.

Björck, S., Håkansson, H., Olsson, S., Barnekow, L. & Janssens, J. 1993. Palaeoclimatic studies in South Shetland Islands, Antarctica, based on numerous stratigraphic variables in lake sediments. *Journal of Paleolimnology*, **8**, 233–272.

Björck, S., Hakansson, H., Zale, R., Karlén, W. & Jönsson, B.L. 1991a. A late Holocene lake sediment sequence from Livingston Island, South Shetland Islands, with palaeoclimatic implications. *Antarctic Science*, **3**, 61–72.

Björck, S., Hjort, C., Ingolfsson, O., Zale, R. & Ising, J. 1996. Holocene deglaciation chronology from lake sediments. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000*. Cambridge: British Antarctic Survey, 49–51.

Bonner, W.N. & Lewis Smith, R.I., *eds*. 1985. *Conservation areas in the Antarctic*. Cambridge: SCAR, 298 pp.

Cabaleri, N., Parica, C., Remesal, M., Salani, F. & Valencio, S. 1997. The lava-sedimentary Mesozoic association of lacustrine environment of Byers Peninsula, South Shetland Islands. *In* Ricci, C.A., *ed. The Antarctic Region: geological evolution and processes*. Siena: Terra Antartica Publications, 361–366.

Cabrerizo, A., Dachs, J., Barceló, D. & Jones, K.C. 2012. Influence of organic matter content and human activities on the occurrence of organic pollutants in Antarctic soils, lichens, grass, and mosses. *Environmental Science & Technology*, **46**, 1396–1405.

Calvet, J., Pallàs, R., Sàbat, F. & Vilaplana, J.M. 1994. Dating ash-layers in glaciers of Livingston Island. *In* Cacho, J. & Serrat, D., *eds. Actas del V Simposio Español de Estudios Antárticos*. Madrid: Comisión Interministerial de Ciencia y Tecnología, 195–208.

Camacho, A. 2006. Planktonic microbial assemblages and the potential effects of metazooplankton predation on the food web of lakes from the maritime Antarctica and sub-Antarctic islands. *Reviews in Environmental Science and Bio/Technology*, **5**, 167–185.

Camacho, A. & Fernández-Valiente, E. 2005. Un mundo dominado por los microorganismos: ecología microbiana de los lagos antárticos. *Ecosistemas*, **14**, 66–78.

Camacho, A., Rochera, C., Villaescusa, J.A., Velázquez, D., Toro, M., Rico, E., Fernández-Valiente, E., Justel, A., Bañón, M. & Quesada, A. In press. Maritime Antarctic lakes as sentinels of climate change. *International Journal of Design & Nature and Ecodynamics*.

Cantrill, D.J. & Poole, I. 2005. Taxonomic turnover and abundance in Cretaceous to Tertiary wood floras of Antarctica: implications for changes in forest ecology. *Palaeogeography Palaeoclimatology Palaeoecology*, **215**, 205–219.

Casanovas, P., Lynch, H. & Fagan, W.F. 2012. Multi-scale patterns of moss and lichen richness on the Antarctic Peninsula. *Ecography*, 10.1111/j.1600-0587.2012.07549.x.

Césari, S.N. 2006. Aptian ferns with *in situ* spores from the South Shetland Islands, Antarctica. *Review of Palaeobotany and Palynology*, **138**, 227–238.

Césari, S.N., Parica, C., Remesal, M. & Salani, F. 1998. First evidence of Pentoxylales in Antarctica. *Cretaceous Research*, **19**, 733–743.

Césari, S.N., Parica, C., Remesal, M. & Salani, F. 1999. Paleofloras del cretácico inferior de Península Byers, Isla Livingston, Antártida. *Ameghiniana*, **36**, 3–22.

Convey, P., Greenslade, P., Richard, K.J. & Block, W. 1996. The terrestrial arthropod fauna of the Byers Peninsula, Livingston Island, South Shetland Islands: Collembola. *Polar Biology*, **16**, 257–259.

Covacevich, V. 1976. Fauna Valanginiana de Peninsula Byers, Isla Livingston, Antarctica. *Revista Geológica de Chile*, **3**, 25–56.

Crame, J.A. 1984. Preliminary bivalve zonation of the Jurassic-Cretaceous boundary in Antarctica. *In* Perrilliat, M.C., *ed. Memoria, III Congreso Latinamerico de Paleontologia*. México, DF: Universidad Nacional Autónoma de Mexico, Instituto de Geología, 242–254.

Crame, J.A. 1995. A new Oxytomid bivalve from the Upper Jurassic–Lower Cretaceous of Antarctica. *Palaeontology*, **39**, 615–628.

Crame, J.A. & Kelly, S.R.A. 1995. Composition and distribution of the Inoceramid bivalve genus Anopaea. *Palaeontology*, **38**, 87–103.

Crame, J.A., Pirrie, D., Crampton, J.S. & Duane, A.M. 1993. Stratigraphy and regional significance of the Upper Jurassic–Lower Cretaceous Byers Group, Livingston Island, Antarctica. *Journal of the Geological Society of London*, **150**, 1075–1087.

Cross, R., Borgatti, S.P. & Parker, A. 2002. Making invisible work visible: using social network analysis to support strategic collaboration. *California Management Review*, **44**, 25–46.

Cuchí, J.A., Durán, J.J., Alfaro, P., Serrano, E. & López-Martínez, J. 2004. Discriminant physicochemical properties of various waters in a permafrost area of the Byers Peninsula (Livingston Island, western Antarctica). *Boletín de la Real Sociedad Española de Historia Natural, Sección Geologica*, **99**, 75–82.

Curl, J.E. 1980. *A glacial history of the South Shetland Islands, Antarctica*. Columbus, OH: The Ohio State University, Institute of Polar Studies, Report 63, 168–176.

Dalziel, I.W.D., Price, D.P. & Stirewalt, G.L. 1970. Structural studies in the Scotia Arc: Elephant Island, Gibbs Island, Hope Bay, and Livingston Island. *Antarctic Journal of United States*, **5**(4), 100–101.

Dastidar, P.G. 2007. National and institutional productivity and collaboration in Antarctic science: an analysis of 25 years of journal publications. *Polar Science*, **26**, 175–180.

Davey, M.C. 1993a. Carbon and nitrogen dynamics in a maritime Antarctic stream. *Freshwater Biology*, **30**, 319–330.

Davey, M.C. 1993b. Carbon and nitrogen dynamics in a small pond in the maritime Antarctic. *Hydrobiologia*, **257**, 165–175.

De Pablo, M.A., Ramos, M., Vieira, G. & Quesada, A. 2010. A new CALM-S site on Byers Peninsula, Livingston Island, Antarctica. *In* Blanco, J.J., De Pablo, M.A. & Ramos, M., *eds. Ambientes periglaciares, permafrost y variabilidad Climática: II Congreso Ibérico de la International Permafrost Association*. Alcalá de Henares: Servicio de Publicaciones de la Universidad de Alcalá, 153–159.

De Pablo, M.A., Blanco, J.J., Molina, A., Ramos, M., Vieira, G. & Quesada, A. 2013. Interannual active layer variability at the Limnopolar Lake CALM Site, Byers Peninsula, Livingston Island, Antarctica. *Antarctic Science*, **25**, 10.1017/S0954102012000818.

Demant, A., Touron, S., Lapierre, H. & Bosch, D. 2004. Cretaceous arc volcanism of Byers Peninsula, Livingston Island, Antarctica: new petrological, geochemical and isotope data. *Bulletin de la Société Géologique de France*, **175**, 131–145.

Doran, P.T. & Vincent, W.F. 2012. Environmental protection and stewardship of subglacial aquatic environments. *Geophysical Monograph Series*, **192**, 149–157.

Duane, A.M. 1994. Preliminary palynological investigation of the Byers Group (Late Jurassic–Early Cretaceous), Livingston Island, Antarctic Peninsula. *Review of Palaeobotany and Palynology*, **84**, 113–120.

Duane, A.M. 1996. Palynology of the Byers Groups (Late Jurassic–Early Cretaceous) of Livingston and Snow islands, Antarctic Peninsula: its biostratigraphical and palaeoenvironmental significance. *Review of Palaeobotany and Palynology*, **91**, 241–281.

Duane, A.M. 1997. Taxonomic investigations of palynomorphs from the Byers Group (Upper Jurassic-Lower Cretaceous), Livingston and Snow islands, Antarctic Peninsula. *Palynology*, **21**, 123–144.

Edwards, M. & Usher, M.B. 1985. The winged Antarctic midge *Parochlus steineni* (Gerke) (Diptera:Chironomidae) in the South Shetland Islands. *Biological Journal of the Linnean Society*, **26**, 83–93.

Ellis-Evans, J.C. 1996. Biological and chemical features of lakes and streams. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000*. Cambridge: British Antarctic Survey, 20–22.

Emslie, S.D., Baumann, K. & van Tuinen, M. 2011. Late Holocene occupation of gentoo penguins (*Pygoscelis papua*) on Byers Peninsula, Livingston Island, Antarctica. *Polar Biology*, **34**, 283–290.

Emslie, S.D., Politto, M.J. & Patteron, W.P. 2013. Stable isotope analysis of ancient and modern gentoo penguin egg membrane and the krill surplus hypothesis in Antarctica. *Antarctic Science*, **25**, 10.1017/S0954102012000740.

Everett, K.R. 1971. Observations on the glacial history of Livingston Island. *Arctic*, **24**, 41–50.

Falcon-Lang, H.J. & Cantrill, D.J. 2001. Gymnosperm woods from the Cretaceous (mid-Aptian) Cerro Negro Formation, Byers Peninsula, Livingston Island, Antarctica: the arborescent vegetation of a volcanic arc. *Cretaceous Research*, **22**, 277–293.

Falcon-Lang, H.J. & Cantrill, D.J. 2002a. Terrestrial paleoecology of the Cretaceous (early Aptian) Cerro Negro Formation, South Shetlands Islands, Antarctica: a record of polar vegetation in a volcanic arc environment. *Palaios*, **17**, 491–506.

Falcon-Lang, H.J. & Cantrill, D.J. 2002b. Terrestrial palaeoecology of an Early Cretaceous volcanic archipelago, Byers Peninsula and President Head, South Shetlands Islands, Antarctica. *Palaios*, **17**, 535–549.

Fassnacht, S.R. & Toro, M. 2013. Mapping snow cover and snow depth across the lake limnopolar watershed on Byers Peninsula, Livingston Island, in maritime Antarctica. *Antarctic Science*, **25**, 10.1017/S0954[redacted].

Fassnacht, S.R., Toro-Velasco, M., Meiman, P.J. & Whitt, Z.C. 2010. The effect of aeolian deposition on the surface roughness of melting snow, Byers Peninsula, Antarctica. *Hydrological Processes*, **24**, 2007–2013.

Fernández-Valiente, E., Camacho, A., Rochera, C., Rico, E., Vincente, W.F. & Quesada, A. 2007. Community structure and physiological characterization of microbial mats in Byers Peninsula, Livingston Island (South Shetland Islands, Antarctica). *FEMS Microbiology Ecology*, **59**, 377–385.

Francis, J.E. 1986. Growth rings in Cretaceous and Tertiary wood from Antarctica and their paleoclimatic implications. *Palaeontology*, **29**, 665–684.

Gibson, J.A.E., Cromer, L., Agius, J.T., McInnes, S.J. & Marley, N.J. 2007. Tardigrade eggs and exuviae in Antarctic lake sediments: insights into Holocene dynamics and origins of the fauna. *In* Pilato, G. & Rebecchi, L., *eds.* Proceedings of the Tenth International Symposium on Tardigrada. *Journal of Limnology*, **66**(S1), 65–71.

Gil-Delgado, J.A., González-Solís, J. & Barbosa, A. 2013. Populations of breeding birds in Byers Peninsula, Livingston Island, South Shetlands Islands. *Antarctic Science*, **25**, 10.1017/S0954102012000752.

González-Casado, J.M., López-Martínez, J., Durán, J.J. & Gergamín, J.F. 1997. Fracturación y campos de esfuerzos recientes en el entorno del Estrecho de Bransfield, Antártida Occidental. *Boletín de la Real Sociedad Española de Historia Natural* (*Sección Geología*), **93**, 181–188.

González-Ferrán, O., Katsui, Y. & Tavera, J. 1970. Contribución al conocimiento geológico de la Península Byers, Isla Livingston, Islas Shetland del Sur, Antártica. *Instituto Antártico Chileno, Serie Cientifica*, **1**, 41–54.

Gracanin, T.M. 1983. *Geochemistry and geochronology of some Mesozoic igneous rocks from the northern Antarctic Peninsula region*. MSc thesis, Ohio State University, 386 pp. [Unpublished]

Gray, N.F. & Smith, R.I.L. 1984. The distribution of nematophagous fungi in the maritime Antarctic. *Mycopathologia*, **85**, 81–92.

Greene, S.W., Gressitt, J.L., Korb, D., Llano, G.A., Rudolph, E.D., Singer, R., Steere, W.C. & Ugolini, F.C. 1967. Terrestrial life in Antarctica. *Antarctic Map Folio Series*, **5**, 11 plates.

Gregory, M.R. & Ryan, P.G. 1997. Pelagic plastics and other seaborne persistent synthetic debris: a review of Southern Hemisphere perspectives. *In* Coe, J.M. & Rogers, D.B., *eds*. *Marine debris: sources, impacts and solutions*. New York: Springer, 49–66.

Grunow, A.M. 1993. New paleomagnetic data from the Antarctica Peninsula and their tectonic implications. *Journal of Geophysical Research. Solid Earth,*, **98**, 13 815–13 833.

Hall, B.L. 2003. An overview of late Pleistocene glaciation in the South Shetland Islands. *Antarctic Research Series*, **79**, 103–113.

Hall, B.L. 2010. Holocene relative sea-level changes and ice fluctuations in the South Shetland Islands. *Global and Planetary Change*, **74**, 15–26.

Hall, B.L. & Perry, E.R. 2004. Variations in ice-rafted detritus on beaches in the South Shetland Islands: a possible climate proxy. *Antarctic Science*, **16**, 339–344.

Hall, B.M. 2009. Holocene glacial history of Antarctica and sub-Antarctic Islands. *Quaternary Science Reviews*, **28**, 2213–2230.

Hall, K.J. 1992a. Mechanical weathering on Livingston Island, South Shetland Islands, Antarctica. *In* Yoshida, Y., Kaminuma, K. & Shiraishi, K., *eds*. *Recent progress in Antarctic earth science*. Tokyo: Terra Scientific Publishing Company, 757–762.

Hall, K.J. 1992b. Mechanical weathering in the Antarctic: a maritime perspective. *In* Dixon, J.C. & Abrahams, A.D., *eds*. *Periglacial geomorphology*. Chichester: Wiley, 103–123.

Hall, K.J. 1993a. Enhanced bedrock weathering in association with late-lying snowpatches: evidence from Livingston Island, Antarctica. *Earth Surface Processes and Landforms*, **18**, 121–129.

Hall, K.J. 1993b. Rock temperatures from Livingston Island (maritime Antarctic): implications for cryogenic weathering. *Permafrost Sixth International Conference, Proceedings*. Beijing: South China University of Technology Press, **1**, 220–225.

Hall, K.J. 1994. Some observations regarding sorted stripes, Livingston Island, South Shetland. *Permafrost and Periglacial Processes*, **5**, 119–126.

Hansom, J.D. 1979. Radiocarbon dating of a raised beach at 10 m in the South Shetland Islands. *British Antarctic Survey Bulletin*, No. 49, 287–288.

Hansson, L.A. & Håkansson, H. 1992. Diatom community response along a productivity gradient of shallow Antarctic lakes. *Polar Biology*, **12**, 463–468.

Harris, J.D. 2001. Radiocarbon dating of a raised beach at 10 m in the South Shetland Islands. *British Antarctic Survey Bulletin*, No. 49, 287–288.

Hathway, B. 1997. Non-marine sedimentation in an Early Cretaceous extensional continental-margin arc, Byers Peninsula, Livingston Island, South Shetland Islands. *Journal of Sedimentary Research*, **67**, 686–697.

Hathway, B. & Lomas, S.A. 1998. The Upper Jurassic–Lower Cretaceous Byers Peninsula Group, South Shetland Islands, Antarctica: revised stratigraphy and regional correlations. *Cretaceous Research*, **19**, 43–67.

Hathway, B., Duane, A.M., Cantrill, D.J. & Kelley, S.P. 1999. Ar-40/Ar-39 geochronology and palynology of the Cerro Negro Formation, South Shetland Islands, Antarctica: a new radiometric tie for Cretaceous terrestrial biostratigraphy in the Southern Hemisphere. *Australian Journal of Earth Sciences*, **46**, 593–606.

Henríquez, O.M. 1994. *Soil characterization of the Byers Peninsula, Livingston Island, South Shetland Islands* (*Antarctic*). PhD thesis, Universidad de Chile, Santiago, 102 pp. [Unpublished]

Hernández, P.J. & Azcarate, V. 1971. Estudio paleobotánico preliminar sobre restos de una tafoflora de la Peninsula Byers (Cerro Negro), Isla Livingston, Islas Shetland del Sur, Antártica. *Instituto Antártico Chileno, Serie. Cientifica*, **2**, 15–50.

Hernández-Cifuentes, F. 1994. Geodesy and topography of Livingston and Deception islands. *In* Cacho, J. & Serrat, D., *eds. Actas del V Simposio Español de Estudios Antárticos*. Madrid: Comisión Interministerial de Ciencia y Tecnología, 291–302.

Hernández-Cifuentes, F., López-Martínez, J. & Thomson, M.R.A. 1996. Topographic map. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000*. Cambridge: British Antarctic Survey, 5–8.

Hjort, C., Ingolfsson, O. & Björck, S. 1992. The last major deglaciation in the Antarctic Peninsula Region: a review of recent Swedish Quaternary research. *In* Yoshida, Y., Kaminuma, K. & Shiraishi, K., *eds. Recent progress in Antarctic earth science*. Tokyo: Terra Scientific Publishing Company, 741–743.

Hobbs, E.J. 1968. The geology of the South Shetland Islands, IV. The geology of Livingston Island. *British Antarctic Survey Scientific Reports*, No. 47, 34 pp.

Hodgson, D., Dyson, C.L., Jones, V.J. & Smellie, J.L. 1998. Tephra analysis of sediments from Midge Lake (South Shetland Islands) and Sombre Lake (South Orkney Islands), Antarctica. *Antarctic Science*, **10**, 13–20.

Hughes, K.A. & Convey, P. 2010. The protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. *Global Environmental Change*, **20**, 96–112.

John, B.S. & Sugden, D.E. 1971. Raised marine features and phases of glaciation in the South Shetland Islands. *British Antarctic Survey Bulletin*, No. 24, 45–111.

Jones, V.J., Juggins, S. & Ellins-Evans, J.C. 1993. The relationship between water chemistry and surface sediment diatom assemblages in maritime Antarctic lakes. *Antarctic Science*, **5**, 339–348.

Kiessling, W., Scasso, R., Zeiss, A., Riccardi, A.C. & Medina, F.A. 1999. Combined radiolarian-ammonite stratigraphy for the Late Jurassic of the Antarctic Peninsula: implications for radiolarian stratigraphy. *Geodiversitas*, **21**, 687–713.

Kleinteich, J., Wood, S.A., Küpper, F.C., Camacho, A., Quesada, A., Frickey, T. & Dietrich, D.R. 2012. Temperature related changes in polar cyanobacterial mat diversity and toxin production. *Nature Climate Change*, 10.1038/nclimate1418.

Kopalová, K. & van de Vijver, B. 2013. Structure and ecology of the freshwater diatom communities from Byers Peninsula, Livingston Island, South Shetland Islands. *Antarctic Science*, **25**, 10.1017/S0954102012000764.

Lewis Smith, R.I. 1985. *Nothofagus* and other trees stranded on islands in the Atlantic sector of the Southern Ocean. *British Antarctic Survey Bulletin*, No. 66, 47–55.

Lewis Smith, R.I. & Øvstedal, D.O. 1991. The lichen genus *Stereocaulon* in Antarctica and South Georgia. *Polar Biology*, **11**, 91–102.

Lewis Smith, R.I. & Simpson, H.W. 1987. Early nineteenth century sealer refuges on Livingston Island, South Shetland islands. *British Antarctic Bulletin*, No. 74, 49–72.

Lindsay, D.C. 1969a. Further data on Antarctic Usneaceae. *British Antarctic Survey Bulletin*, No. 20, 23–40.

Lindsay, D.C. 1969b. New records for Antarctic Umbilicariaceae. *British Antarctic Survey Bulletin*, No. 21, 61–69.

Lindsay, D.C. 1971a. Notes on Antarctic lichens: I. New records for *Buellia* and *Rinodina*. *British Antarctic Survey Bulletin*, No. 24, 11–19.

Lindsay, D.C. 1971b. Vegetation of the South Shetland Islands. *British Antarctic Survey Bulletin*, No. 25, 59–83.

Lindsay, D.C. 1973. Notes on Antarctic lichens: Vll. The genera *Cetraria* Hoffm., *Hypogymnia* (Nyl.) Nyl., *Menegazzia* Massal., *Parmelia* Ach. and *Platismatia* Culb. et Culb. *British Antarctic Survey Bulletin*, No. 36, 105–114.

Lomas, S.A. 1999. A Lower Cretaceous clastic slope succession, Livingston Island, Antarctica: sand-body characteristics, depositional processes and implications for slope apron depositional models. *Sedimentology*, **46**, 477–504.

López-Bueno, A., Tamames, J., Velázquez, D., Moya, A., Quesada, A. & Alcami, A. 2009. High diversity of the viral community from an Antarctic lake. *Science*, **326**, 858–861.

López-Martínez, J., Martínez de Pisón, E., Serrano, E. & Arche, A. 1995. *Geomorphological map of Byers Peninsula, Livingston Island. BAS Geomap Series 5-A. Scale 1:25 000*. Cambridge: British Antarctic Survey.

López-Martínez, J., Thomson, M.R.A. & Thomson, J.W 1996a. *Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000 with supplementary text*. Cambridge: British Antarctic Survey, 65 pp.

López-Martínez, J., Hathway, B., Lomas, S., Martínez de Pisón, E. & Arche, A. 1996b. Structural geomorphology and geological setting. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000*. Cambridge: British Antarctic Survey, 9–14.

López-Martínez, J., Serrano, E. & Martínez de Pisón, E. 1996c. Geomorphological features of the drainage system. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000*. Cambridge: British Antarctic Survey, 15–19.

López-Martínez, J., Serrano, E., Schmid, T., Mink, S. & Linés, C. 2012. Periglacial processes and landforms in the South Shetland Islands (northern Antarctic Peninsula region). *Geomorphology*, **155/156**, 62–79.

Lyons, W.B., Welch, K.A., Welch, S.A., Camacho, A., Rochera, C., Michaud, L., Dewit, R. & Carey, A.E. 2013. Geochemistry of streams from Byers Peninsula, Livingston Island. *Antarctic Science*, **25**, 10.1017/S0954102012000776

Machado, A., Chemale, F., Conceição, R.V., Kawaskita, K., Morata, D., Oteíza, O. & van Schmus, W.R. 2005b. Modeling of subduction components in the Genesis of the Meso-Cenozoic igneous rocks from the South Shetland Arc, Antarctica. *Lithos*, **82**, 435–453.

Machado, A., Lima, E.F., Chemale, F., Morata, D., Oteiza, O., Almeida, D.P.M., Figuereido, A.M.G., Alexandre, F.M. & Urrutia, J.L. 2005a. Geochemistry constraints of Mesozoic-Cenozoic calc-alkaline magmatism in the South Shetland Arc, Antarctica. *Journal of South American Earth Sciences*, **18**, 407–425.

Martínez de Pisón, E., Serrano, E., Arche, A. & López-Martínez, J. 1996a. Glacial geomorphology. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000*. Cambridge: British Antarctic Survey, 23–27.

Martínez de Pisón, E., López-Martínez, J., Serrano, E. & Arche, A. 1996b. Geomorphological evolution. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000*. Cambridge: British Antarctic Survey, 52–54.

Matzer, M., Mayrhofer, H. & Scheidegger, C.H. 1994. Notes on *Amandinea petermannii* comb. nov. (Physciaceae) from Antarctica. *Lichenologist*, **26**, 39–46.

Michalchuck, B.R., Anderson, J.B., Wellner, J.S., Manley, P.L., Majewski, W. & Bohaty, S. 2009. Holocene climate and glacial history of the northeastern Antarctic Peninsula: the marine sedimentary record from a long SHALDRIL core. *Quaternary Science Reviews*, **28**, 3049–3065.

Moura, P.A., Francelino, M.R., Schaefer, C.E.G.R., Simas, F.N.B. & de Mendonça, B.A.F. 2012. Distribution and characterization of soils and landform relationships in Byers Peninsula, Livingston Island, Maritime Antarctica. *Geomorphology*, **155/156**, 45–54.

Nakai, R., Shibuya, E., Justel, A., Rixo, E., Quesada, A., Elvevold, S., Holmén, K., Kobayashi, F., Iwasaka, Y., Shi, G.-Y., Amano, Y., Iwatsuki, T. & Naganima, T. 2013. Phylogeographic analysis of filetrable bacteria with special reference to *Rhizobiales* strains that occur in cryospheric habitats. *Antarctic Science*, **25**, 10.1017/S0954102012000831.

Navas, A., Soto, J. & López-Martínez, J. 2005. Radionuclides in soils of Byers Peninsula, South Shetland Islands, Western Antarctica. *Applied Radiation and Isotopes*, **62**, 809–816.

Navas, A., López-Martínez, J., Casas, J., Machín, J., Durán, J.J., Serrano, E. & Cuchi, J.A. 2006. Soil characteristics along a transect on raised marine surfaces on Byers Peninsula, Livingston Island, South Shetland Islands. *In* Fütterer, D.K., Damaske, D., Kleinschmidt, G., Miller, H. & Tessensohn, F., *eds. Antarctica contributions to global earth science*. Berlin: Springer, 467–474.

Navas, A., López-Martínez, J., Casas, J., Machín, J., Durán, J.J., Serrano, E., Cuchi, J.A. & Milk, S. 2008. Soil characteristics on varying lithological substrates in the South Shetland Islands, maritime Antarctica. *Geoderma*, **144**, 123–139.

Nielsen, U.N., Wall, D.H., Li, G., Toro, M., Adams, B.J. & Virginia, R.A. 2011. Nematode communities of Byers Peninsula, Livingston Island, maritime Antarctica. *Antarctic Science*, **23**, 349–357.

Ochyra, R., Lewis Smith, R.I. & Bednarek-Ochyra, H. 2008. *The illustrated moss flora of Antarctica*. Cambridge: Cambridge University Press, 685 pp.

Orheim, O. 1971. Glaciological studies at Deception Island and Livingston Island. *Antarctic Journal of United States*, **6**(4), 85.

Orlando, H.A. 1968. A new Triassic flora from Livingston Island, South Shetland Islands. *British Antarctic Survey Bulletin*, No. 16, 1–13.

Oteiza, O. 1999. *Petrogénesis del magmatismo básico del Meso-Cenozoico en la Península Byers, Isla Livingston (Archipiélago de Shetland del Sur, Antártica)*. MSc thesis, University of Chile, 100 pp. [Unpublished]

Pankhurst, R.J., Weaver, S.D., Brook, M. & Saunders, A.D. 1979. K-Ar chronology of Byers Peninsula, Livingston Island, South Shetland Islands. *British Antarctic Survey Bulletin*, No. 49, 277–282.

Parica, C.A., Salani, F.M., Vera, E., Remesal, M. & Césari, S.N. 2007. Geología de la formación Cerro Negro (Cretácico) en Isla Livingston: aportes a su geocronología y contenido paleontológico. *Revista de la Asociación Geológica Argentina*, **62**, 553–567.

Pearce, D.A. & Laybourn-Parry, J. 2012. Antarctic lakes as models for the study of microbial biodiversity, biogeography and evolution. *In* Rogers, A.D., Johnston, N.M., Murphy, E.J. & Clarke, A., *eds. Antarctic ecosystems: an extreme environment in a changing world*. Chichester: John Wiley, 10.1002/9781444347241.ch3

Pearson, M., Stehberg, R., Zarankin, A., Senatore, M.X. & Gatica, C. 2008. Sealer's sledge excavated on Livingston Island, South Shetland Islands. *Polar Record*, **44**, 362–364.

Pearson, M., Stehberg, R., Zarankin, A., Senatore, M.X. & Gatica, C. 2010. Conserving the oldest historic sites in the Antarctic: the challenges in managing the sealing sites in the South Shetland Islands. *Polar Record*, **46**, 57–64.

Pertierra, L., Hughes, K., Benayas, J., Justel, A. & Quesada, A. 2013a. Research in a field camp in Antarctica: the delicate balance between environmental coasts and scientific benefit. *Antarctic Science*, **25**, 10.1017/S0954[redacted].

Pertierra, L.R., Lara, F., Tejedo, P., Quesada, A. & Benayas, J. 2013b. Rapid denudation processes in cryptogamic communities from Maritime Antarctica subjected to human trampling. *Antarctic Science*, **25**, 10.1017/S095410201200082X

Petz, W., Valbonesi, A. & Quesada, A. 2005. Ciliate biodiversity in freshwater environments of maritime and continental Antarctic. *Terra Antarctica Reports*, **11**, 43–50.

Petz, W., Valbonesi, A., Schiftner, U., Quesada, A. & Ellis-Evans, J.C. 2007. Ciliate biogeography in Antarctic and Arctic freshwater ecosystems: endemism or global distribution of species? *FEMS Microbiology Ecology*, **59**, 396–408.

Pimpirev, C. & Vangelov, D. 1999. Ancient subaqueous mouth bar type delta system, Byers Group, Livingston Island, Antarctica. *Sofia University Yearbook, Faculty of Geology and Geography*, **90**, 29–43.

Pirrie, D. & Crame, J.A. 1995. Late Jurassic paleogeography and anaerobic-dysaerobic sedimentation in the nothern Antarctic Peninsula. *Journal of the Geological Society of London*, **152**, 469–480.

Pla-Rabes, S., Toro, M., van de Vijver, B., Rochera, C., Villaescusa, J.A., Camacho, A. & Quesada, A. 2013. Stability and endemicity of benthic diatom assemblages from different substrates on a maritime stream on Byers Peninsula, Livingston Island, Antarctica: the role of climate variability. *Antarctic Science*, **25**, 10.1017/S0954102012000922.

Poblete, F., Arriagada, C., Roperch, P., Astudillo, N.M., Hervé, F., Kraus, S. & Le-Roux, J.P. 2011. Paleomagnetism and tectonics of the South Shetland Islands and the northern Antarctic Peninsula. *Earth and Planetary Science Letters*, **302**, 299–313.

Quesada, A., Vincent, W.F., Kaup, E., Hobbie, J.E., Laurion, I., Pienitz, R., López-Martínez, J. & Durán, J.J. 2006. Landscape control of high latitude lakes in a changing climate. *In* Bergstrom, D.M., Convey, P. & Huiskes, A.H.L., *eds. Trends in Antarctic terrestrial and limnetic ecosystems*. Dordrecht: Springer, 221–252.

Quesada, A., Fernández-Valiente, E., Hawes, I. & Howard-Williams, C. 2008. Benthic primary production in polar lakes and rivers. *In* Vincent, W.F. & Laybourn-Parry, J., *eds. Polar lakes and rivers: limnology of Arctic and Antarctic aquatic ecosystems*. Oxford: Oxford University Press, 179–196.

Quesada, A., Camacho, A., Rochera, C. & VelÁzquez, D. 2009. Byers Peninsula: a reference site for coastal, terrestrial and limnetic ecosystem studies in maritime Antarctica. *Polar Science*, **3**, 181–187.

Rengifo-Herrera, C., Ortega-Mora, L.M., Gómez-Bautista, M., García-Moreno, G.T., García-Párraga, D., Castro-Urda, J. & Pedraza-Díaz, S. 2011. Detection and characterization of a *Cryptosporidium* isolate from a southern elephant seal (*Mirounga leonina*) from the Antarctic Peninsula. *Applied and Environmental Microbiology*, **77**, 1524–1527.

Richard, K.J., Convey, P. & Block, W. 1994. The terrestrial arthropod fauna of the Byers Peninsula, Livingston-Island, South Shetland Islands. *Polar Biology*, **14**, 371–379.

Rico, E. & Quesada, A. 2013. Distribution and ecology of chironomids (Diptera, Chironomidae) on Byers Peninsula, Maritime Antarctica. *Antarctic Science*, **25**, 10.1017/S095410201200096X.

Rochera, C., Justel, A., Fernández-Valiente, E., Bañón, M., Rico, E., Toro, M., Camacho, A. & Quesada, A. 2010. Interannual meteorological variability and its effects on a lake from maritime Antarctica. *Polar Biology*, **33**, 1615–1628.

Rochera, C., Villaescusa, J.A., Díazmazip, M.E., Gil-Delgado, J.A., Toro, M., Rico, E., Velázquez, D., Quesada, A. & Camacho, A. 2011. Interacciones bióticas en lagos Antárticos. Investigaciones derivadas del proyecto LIMNOPOLAR en la Península Byers (Antártida marítima). *Ecosistemas*, **20**, 23–32.

Rochera, C., Toro, M., Camacho, A., Rico, E., Fernández-Valiente, E., Villaescusa, J.A., Picazo, A., Quesada, A. & Camacho, A. 2013a. Structure of planktonic microbial communities along a trophic gradient in lakes of Byers Peninsula, South Shetland Islands. *Antarctic Science*, **25**, 10.1017/S0954102012000971.

Rochera, C., Villaescusa, J.A., Velázquez, D., Fernández-Valiente, E., Quesada, A. & Camacho, A. 2013b. Vertical structure of bi-layered microbial mats from Byers Peninsula, Maritime Antarctica. *Antarctic Science*, **25**, 10.1017/S0954102012000983.

Rodríguez, P. & Rico, E. 2008. A new freshwater oligochaete species (Clitellata: Enchytraeidae) from Livingston Island, Antarctica. *Polar Biology*, **31**, 1267–1279.

Sancho, L.G., Kappen, L. & Schroeter, B. 1992. The lichen genus *Umbilicaria* on Livingston Island, South Shetland Islands, Antarctica. *Antarctic Science*, **4**, 189–196.

Schiaffino, M.R., Unrein, F., Gasol, J.M., Massana, R., Balagué, V. & Izaguirre, I. 2011. Bacterial community structure in a latitudinal gradient of lakes: the roles of spatial versus environmental factors. *Freshwater Biology*, **56**, 1973–1991.

Serrano, E. 2003. Natural landscape and geoecological belts on ice free areas of the maritime Antarctica (South Shetland Islands). *AGE Bulletin*, **35**, 5–32.

Serrano, E., Martínez de Pisón, E. & López-Martínez, J. 1996. Periglacial and nival landforms and deposits. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000*. Cambridge: British Antarctic Survey, 28–34.

SGE, UAM & BAS. 1993. *Byers Peninsula, Livingston Island. Topographic map, Antarctic Cartography, Scale 1:25 000*. Madrid: Servicio de Geografía del Ejército, Universidad Autónoma de Madrid and British Antarctic Survey.

Smellie, J.L., Davies, R.E.S. & Thomson, M.R.A. 1980. Geology of a Mesozoic intra-arc sequence on Byers Peninsula, Livingston Island, South Shetland Islands. *British Antarctic Survey Reports*, No. 50, 55–76.

Stehberg, R. 2008. Protection and preservation of the oldest sites of the Antarctic; the case of Fildes Peninsula and Byers Peninsula in the South Shetland Islands. *In* Baar, S. & Chaplin, P., *eds. Historical Polar bases; preservation and management*. Oslo: International Polar Heritage Committee, 85–93.

Stehberg, R., Pearson, M., Blanchette, R. & Jurgens, J.A. 2009. A further note on a sealer's sledge, discovered on Livingston Island, South Shetland Islands. *Polar Record*, **45**, 275–275.

Sugden, D.E. & John, B.S. 1973. The ages of glacier fluctuations in the South Shetland Islands, Antarctica. *In* van Zinderen, E.M., *ed. Paleoecology of Africa and of the surrounding islands and Antarctica*. Cape Town: Balkema, 141–159.

Tejedo, P., Justel, A., Rico, E., Benayas, J. & Quesada, A. 2005. Measuring impacts on soils by human activity in an Antarctic Special Protected Area. *Terra Antartica Reports*, **11**, 57–62.

Tejedo, P., Justel, A., Benayas, J., Rico, E., Convey, P. & Quesada, A. 2009. Soil trampling in an Antarctic Specially Protected Area: tools to assess levels of human impact. *Antarctic Science*, **21**, 229–236.

Tejedo, P., Pertierra, L., Benayas, J., Convey, P., Justel, A. & Quesada, A. In press. Trampling on maritime Antarctica: can soil ecosystems be effectively protected through existing codes of conduct? *Polar Research.*

Thom, G. 1978. Disruption of bedrock by the growth and collapse of ice lenses. *Journal of Glaciology*, **20**, 571–575.

Thomson, M.R.A. 1992. Stratigraphy and age of the Pre-Cenozoic stratified rocks of the South Shetland Islands: review. *In* López-Martínez, J., *ed. Geología de la Antártida Occidental. Simposios Tomo 3. III Congreso Geológico de España y VII Congreso Latinoamericano de Geología*. Madrid: Comisión Interministerial de Ciencia y Tecnología, 75–92.

Thomson, M.R.A. & López-Martínez, J. 1996. Geomorphological map of Byers Peninsula, Livingston Island; introduction. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000*. Cambridge: British Antarctic Survey, 1–4.

Toro, M., Camacho, A., Rico, E., Rochera, C., Velazquez, D., Dominguez, J.A. & Quesada, A. 2008. Implicaciones del cambio climático en el funcionamiento de los ecosistemas antárticos: los lagos como centinelas de la variación ambiental. *Ingeniería Civil*, **149**, 1–12.

Toro, M., Granados, I., Pla, S., Giralt, S., Antoniades, D., Galán, L., Martínez Cortizas, A., Lim, H.S. & Appleby, P.G. 2013. Chronostratigraphy of the sedimentary record of Limnopolar Lake, Byers Peninsula, Livingston Island, Antarctica. *Antarctic Science*, **25**, 10.1017/S095410202000788.

Toro, M., Camacho, A., Rochera, C., Rico, E., Bañon, M., Fernandez-Valiente, E., Marco, E., Justel, A., Avendano, M.C., Ariosa, Y., Vincent, W.F. & Quesada, A. 2007. Limnological characteristics of the freshwater ecosystems of Byers Peninsula, Livingston Island, in maritime Antarctica. *Polar Biology*, **30**, 635–649.

Torres, T.G., Valenzuela, E. & Gonzalez, I. 1982. Paleoxilologia de peninsula Byers, Isla Livingston, Antarctica. *Actas III Congreso Geológico Chileno*, **2**, 321–342.

Upson, R., Read, D.J. & Newsham, K.K. 2007. Widespread association between the ericoid mycorrhizal fungus Rhizoscyphus ericae and a leafy liverwort in the maritime and sub-Antarctic. *New Phytologist*, **176**, 460–471.

Valenzuela, E. & Hervé, F. 1972. Geology of Byers Peninsula, Livingston Island, South Shetland Islands. *In* Adie, R.J., *ed. Antarctic geology and geophysics*. Oslo: Universitetsforlaget, 83–89.

Van de Vijver, B. & Zidarova, R. 2011. Five new taxa in the genus *Pinnularia* sectio *Distantes* (Bacillariophyta) from Livingston Island (South Shetland Islands). *Phytotaxa*, **24**, 39–50.

Van de Vijver, B., Agius, J.T., Gibson, J.A.E. & Quesada, A. 2009. An unusual spine-bearing *Pinnularia* species from the Antarctic Livingston Island (South Shetland Islands). *Diatom Research*, **24**, 431–441.

Van de Vijver, B., Zidarova, R. & De Haan, M. 2011. Four new *Luticol*a taxa (Bacillariophyta) from the South Shetland Islands and James Ross Island (Maritime AntarcticRegion). *Nova Hedwigia*, **92**, 137–158.

Velázquez, D., Rochera, C., Camacho, A. & Quesada, A. 2011. Temperature effects on carbon and nitrogen metabolism in some Maritime Antarctic freshwater phototrophic communities. *Polar Biology*, **34**, 1045–1055.

Velázquez, D., Frías, A., Lezcano, M.A. & Quesada, A. 2013. Ecological relationships and stoichiometry within a maritime Antarctic watershed. *Antarctic Science*, **25**, 10.1017/S0954102012000843.

Vera, E.I. 2007. A new species of *Ashicaulis* Tidwell (Osmundaceae) from Aptian strata of Livingston Island, Antarctica. *Cretaceous Research*, **28**, 500–508.

Vera, E.I. 2009. *Alienopteris livingstonensis* gen. et sp nov., enigmatic petrified tree fern stem (Cyatheales) from the Aptian Cerro Negro Formation, Antarctica. *Cretaceous Research*, **30**, 401–410.

Vera, E.I. 2010. A new specimen of *Millerocaulis* (Osmundales: Osmundaceae) from the Cerro Negro Formation (Lower Cretaceous), Antarctica. *Revista del Museo Argentino de Ciencias Naturales "Bernardino Rivadavia", nueva serie*, **12**, 41–46.

Vera, E.I. 2011. *Livingstonites gabrielae* gen. et sp. nov., permineralized moss (Bryophyta: Bryopsida) from the Aptian Cerro Negro formation of Livingston Island (South Shetland Islands, Antarctica). *Ameghiniana*, **48**, 122–128.

Vera, E.I. 2012. *Millerocaulis tekelili* sp. nov., a new species of osmundalean fern from the Aptian Cerro Negro Formation (Antarctica). *Alcheringa*, **36**, 35–45.

Vera, M. 2013. Distribution and reproductive capacity of *Deschampsia antarctica* and *Colobanthus quitensis* on Byers Peninsula, Livingston Island, South Shetland Islands, Antarctica. *Antarctic Science*, **25**, 10.1017/S0954102012000995.

Vieira, G., Bockheim, J., Guglielmin, M., Balks, M., Abramov, A.A., Boelhouwers, J., Cannone, N., Ganzert, L., Gilichinsky, D.A., Goryachkin, S., López-Martínez, J., Meiklejohn, I., Raffi, R., Ramos, M., Schaefer, C., Serrano, E., Simas, F., Sletten, R. & Wagner, D. 2010. Thermal state of permafrost and active-layer monitoring in the Antarctic: advances during the International Polar Year 2007–2009. *Permafrost and Periglacial Processes*, **21**, 182–197.

Villaescusa, J.A., Casamayor, E.O., Rochera, C., Velazquez, D., Chicote, A., Quesada, A. & Camacho, A. 2010. A close link between bacterial community composition and environmental heterogeneity in maritime Antarctic lakes. *International Microbiology*, **13**, 67–77.

Villaescusa, J.A., Casamayor, E.O., Rochera, C., Quesada, A., Michaud, L. & Camacho, A. 2013. Heterogeneous vertical structure of the bacterioplankton community in a non-stratified Antarctic lake. *Antarctic Science*, **25**, 10.1017/S0954102012000910.

Vincent, W.F., Hobbie, J.E. & Laybourn-Parry, J. 2008. Introduction to the limnology of high latitude lake and river ecosystems. *In* Vincent, W.F. & Laybourn-Parry, J., *eds*. *Polar lakes and rivers: limnology of Arctic and Antarctic aquatic ecosystems*. Oxford: Oxford University Press, 1–23.

Vincent, W.F. & Quesada, A. 2012. Cyanobacteria in high latitude lakes, rivers and seas. *In* Whitton, B.A., *ed*. *Ecology of cyanobacteria II: their diversity in space and time*. Dordrecht: Springer, 371–385.

Watts, D.R., Watts, G.C. & Bramall, A.M. 1984. Cretaceous and Early Tertiary paleomagnetic results from the Antarctic Peninsula. *Tectonics*, **3**, 333–346.

Wirtz, N., Lumbsch, H.T., Green, T.G.A., Türk, R., Pintado, A., Sancho, L. & Schroeter, B. 2003. Lichen fungi have low cyanobiont selectivity in maritime Antarctica. *New Phytologist*, **160**, 177–183.

Yoo, C.M. & Choe, M.Y. 2000. Provenance of the Lower Cretaceous President Beaches Formation, Livingston Island, South Shetland Islands, West Antarctica. *Korean Journal of Polar Research*, **11**, 27–34.

Zarankin, A. & Senatore, M.X. 2005. Archaeology in Antarctica: nineteenth-century capitalism expansion strategies. *International Journal of Historical Archaeology*, **9**, 43–56.

Zheng, X.S., Liu, J., Lee, J.I. & Hwang, J. 1998a. Geochemical characteristics of the Mesozoic volcanic rocks from the Byers Peninsula of Livingston Island, West Antarctica. *Acta Petrologica Sinica*, **14**, 503–519. [In Chinese with English summary].

Zheng, X.S., Sàbat, F., Casas, J.M. & Pallàs, R. 1995. Volcanic geology of Livingston Island, West Antarctica: a summary. *Antarctic Research*, **7**, 18–29. [In Chinese with English summary].

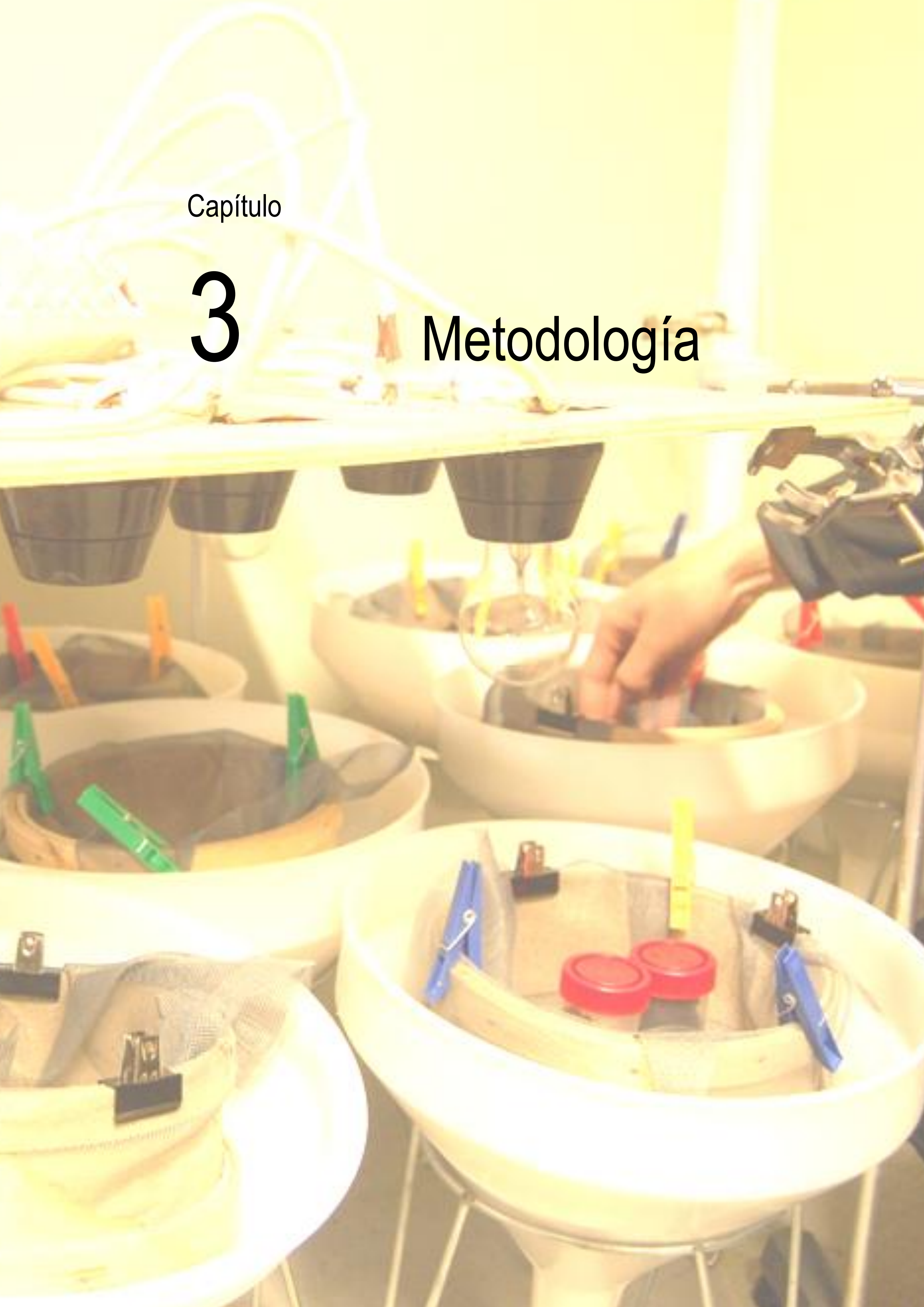
Zheng, X.S., Sang, H.Q., Qiu, J., Liu, J., Lee, J.I. & Hwang, J. 1998b. Isotopic age of the volcanic rock in Byers Peninsula, Livingston Island, West Antarctica. *Chinese Journal of Polar Research*, **10**, 1–10. [In Chinese with English summary]

Zidarova, R., van de Vijver, B., Quesada, A. & De Haan, M. 2010. Revision of the genus *Hantzschia* (Bacillariophyceae) on Livingston Island (South Shetland Islands, Southern Atlantic Ocean). *Plant Ecology and Evolution*, **143**, 318–333.

Zidarova, R., Kopalová, K. & van de Vijver, B. 2012. The genus *Pinnularia* (Bacillariophyta) excluding the section *Distantes* on Livingston Island (South Shetland Islands) with the description of twelve new taxa. *Phytotaxa*, **44**, 11–37.

Capítulo

3 Metodología



Metodología

3.1 APROXIMACIONES METODOLÓGICAS

Los estudios recogidos en la presente tesis se engloban dentro del marco teórico de la Ecología Recreativa, valiéndose de su cuerpo de conocimiento y sus aproximaciones a los problemas ambientales en espacios naturales protegidos (Hammitt & Cole 1998). La Antártida encaja en este modelo siendo el mayor espacio protegido del planeta, con los investigadores, técnicos y turistas actuando como los visitantes del espacio. Sus actividades y las alteraciones que generan son tratadas por medio de las estrategias definidas por la Ecología Recreativa, con objetivo de realizar una ocupación y uso del territorio de forma que permita garantizar la conservación de los recursos naturales que acoge (Leung & Marion 2000). Esta aproximación ha sido implementada y desarrollada en el panorama antártico dentro del grupo de investigación por los estudios doctorales de Tejedo (2012) sirviendo de referencia básica. Por ello no se pretende hacer en este trabajo una recopilación exhaustiva de los preceptos de la ecología recreativa, sino destacar los elementos clave en la construcción de las investigaciones específicas.

3.1.1 Monitoreo ambiental a través de un sistema de Indicadores

En primer lugar destacar el concepto de Monitoreo Ambiental por el cual se recoge información de los sistemas naturales para inferir conocimiento sobre su estado. Debido a la limitaciones impuestas en la toma de datos, particularmente en el continente antártico, así como su interpretación, es necesario seleccionar cuidadosamente los parámetros que se van a recoger y evaluar. La complejidad de los sistemas naturales hace que para su seguimiento sea necesario simplificar la información a través del uso de indicadores (Noss 1999). Se trata de variables cualitativas o cuantitativas, o bien de relaciones entre variables (índices), que proporcionan información útil acerca de la evolución del sistema en el que están inmersas. Los indicadores se pueden aplicar tanto para el seguimiento de ecosistemas y hábitats, como para la valoración de equipamientos o actividades humanas. En ambos casos, contribuyen a construir un panorama de la situación y las tendencias en el estado de los objetos de estudio, al tiempo que proporcionan información útil para evaluar hasta qué punto la gestión aplicada ha sido eficaz (Hockings *et al.* 2006). Constituyen las principales herramientas de los planes de seguimiento y a través de la información obtenida se puede optimizar la toma de decisiones y mejorar los servicios al informar sobre el cumplimiento de los objetivos, los resultados y las actividades previstos. Los indicadores van a ser de gran ayuda para aislar elementos o problemas claves y proporcionar una visión sobre algunas tendencias o su evolución en el tiempo. El análisis de estas tendencias en diferentes momentos permitirá realizar un diagnóstico preciso sobre si las actuaciones o medidas de gestión aplicadas son las apropiadas. También pueden servir para estandarizar datos y establecer comparaciones con los problemas y modelos de gestión aplicados en otros territorios con casuísticas similares.

En el ámbito antártico tanto la dificultad técnica adicional de recabar información en sistemas remotos unida al requerimiento ético de mínima perturbación hace necesario el uso de indicadores que permite abordar de manera eficaz el seguimiento ambiental necesario para apoyar las políticas de conservación. Los preceptos básicos para la constitución de indicadores han sido definidos por el SCAR/COMNAP (ATCM 2006) En la presente tesis se han abordado múltiples indicadores dentro de este paraguas para la consecución de los distintos objetivos específicos, cuyo éxito de aplicación ha sido diverso por multitud de variables. Algunos indicadores han sido sugeridos y promovidos específicamente para la Antártida (bien presentados por delegaciones en la reuniones del Tratado Antártico, o bien en estudios metodológicos) mientras que otros han sido transferidos de otros ámbitos (típicamente del ártico y de zona alpinas). No por ello los indicadores aquí empleados son considerados los únicos o los más apropiados, y a menudo responden a limitaciones logísticas, temporales o espaciales, pero si se consideran potenciales candidatos ya que siguen los preceptos básicos de validez científica, sencillez, fiabilidad, representatividad, disponibilidad, sensibilidad a cambios, relevancia y comparabilidad.

3.1.2 La capacidad de carga y el modelo analítico FPEIR

En segundo lugar señalar el concepto de Capacidad de Carga, o número de personas que puede acoger un espacio sin deteriorar la calidad ambiental (Benayas et al. 2006, 2007) como otro elemento clave entorno al que giran las presentes investigaciones. En unos casos centrándose en la resiliencia propia de distintos ecosistemas o capacidad de carga ecológica ante determinadas actividades, en otros centrándose en la cuantificación de las cargas de presión existentes de distintas actividades, o bien en las medidas de gestión para limitar estas cargas y proteger las condiciones de los ecosistemas. En este sentido la aplicación de indicadores de seguimiento no es útil en ausencia de un marco de referencia que contribuya a explicar el enfoque de trabajo, clarificar las medidas a realizar y los indicadores a utilizar, y que permita comprender cómo se relacionan los indicadores entre sí (Pintér *et al.*, 2005). Los primeros modelos se basaban en la identificación de relaciones *Causa-Efecto*, pero pronto fueron sustituidos por el marco de referencia *Presión-Estado-Respuesta* (PER). Como evolución natural de este modelo, surge el marco de referencia *Fuerza Conductora-Presión-Estado-Impacto-Respuesta* (FPEIR), el cual ha sido adoptado por la Agencia Europea del Medio Ambiente para describir las interacciones entre las sociedades humanas y el medio ambiente (EUROSTAT, 1999). En este caso, las *Fuerzas Conductoras* son actividades humanas que afectan a la salud de los ecosistemas, tanto positiva como negativamente. Estas fuerzas provocarían una *Presión* sobre el medio ambiente, por ejemplo a través de la ocupación de ciertas áreas o del consumo de un recurso. Estos usos pueden degradar el *Estado* de los ecosistemas, provocando cambios observables en sus características que darían lugar a uno o varios *Impactos*. Ante estas alteraciones, es posible dar una *Respuest*a a través de medidas políticas, legislativas, económicas, educativas, etc. Este último marco de referencia ha sido seleccionado para su aplicación en la presente tesis, ya que permite un mayor nivel de detalle en el análisis de los impactos humanos generados sobre los ecosistemas antárticos.

A través de este modelo analítico se integra de manera coherente y ordenada la información que engloba la interacción directa entre los sistemas naturales en zonas libres de hielo y los visitantes humanos. En primer cuerpo de estudios recoge toda la información sobre las distintas actividades humanas generadoras de impactos en estos espacios (típicamente turismo e investigación y su soporte) y su carga de presión espacial y temporal. Por otro lado un segundo bloque recoge la información sobre el estado natural o afectado de los ecosistemas en zonas libres de hielo, habiendo seleccionado los principales componentes bióticos amenazados a través de ejemplos representativos de las extensiones de vegetación nativa o de las colonias de fauna presentes. A su vez un tercer bloque integra el cuerpo de información sobre las actividades de protección ambiental que buscan generar una respuesta de conservación. Aunque estos bloques analíticos aparecen reiteradamente a lo largo de la tesis, los primeros capítulos de resultados se centran principalmente sobre el estado e impactos en distintos componentes de los ecosistemas terrestres (capítulos 4.1, 4.2 y 4.3), mientras que los siguientes se focalizan sobre las fuerzas conductoras, la carga de presión y las estrategias de respuesta (capítulos 4.4. 4.5 y 4.6).

3.2 DISEÑO DE LAS INVESTIGACIONES

Los diseños de las investigaciones responden a los modelos habituales de la Ecología Recreativa, agrupados por Leung & Marion (2000) en:

1) Estudios experimentales. Realizados en condiciones controladas, tienen la finalidad de establecer la magnitud de un impacto ante una intensidad de presión establecida (p.ej. Tejedo et al. 2009 sobre la simulación de pisoteo en suelos antárticos desnudos). Es el diseño propio del capítulo 4.1.

2) Estudios descriptivos. Toman medidas para evaluar las condiciones actuales, se identifican presiones, impactos y sus consecuencias (Benayas et al. 2006). Es un enfoque empleado en todos los capítulos, y el diseño central de los capítulos 4.2 y 4.4.

3) Estudios de comparativa. Se miden lugares impactados y no impactados para determinar la magnitud de los impactos (p.ej. Tejedo et al. 2013 sobre la comparativas de senderos en sitios de visita). Es el diseño propio del capítulo 4.3.

4) Estudios de seguimiento de impactos. Busca establecer como varían las condiciones de un sistema a lo largo de un tiempo, con medidas a lo largo de una actividad gestión (p.ej. Tejedo 2013). Es un enfoque empleado en los capítulos 4.4 y 4.6 y el diseño central del capítulo 4.5.

5) **Estudios de simulación**. Se construyen modelos en base a distintas actividades o procesos prolongados en el tiempo para realizar predicciones sobre el comportamiento de los sistemas (MEA 2005). Es un enfoque empleado en todos los capítulos, y el diseño central de los capítulos 4.2 y 4.6.

Estos diseños se aplican incidiendo en los distintos elementos del modelo analítico PFEIR para generar un cuerpo de conocimiento global de los problemas ambientales, y en particular de los elementos menos estudiados o que suponen mayores retos para el entendimiento y manejo efectivo de los impactos. A continuación se relata el punto de inicio sobre varios problemas ambientales que da pie a la conformación de las investigaciones. Las metodologías específicas de cada trabajo de investigación se describen pormenorizadamente en los artículos que constituyen el Capítulo 4 (Resultados), por lo que en esta sección se limita a describir las aproximaciones realizadas y los diseños específicos finalmente abordaros para alcanzar las principales metas propuestas.

Investigación I. Simulación de pisoteo experimental. El presente estudio, centrado en el estado de las comunidades terrestres vegetales, trata de identificar, caracterizar y comparar comunidades sensibles al pisoteo para definir distintos estados de alteración por medio de indicadores. Existe poco conocimiento sobre la vulnerabilidad de estas comunidades y su capacidad de carga, por ello se escogió un diseño experimental como aproximación fundamental de estudio. No obstante como diseño complementario se realizaron trabajos de comparativa en Isla Barrientos (cap. 5.1.1).

De tal manera en la campaña 2009-10, en colaboración directa con el grupo de investigación Limnopolar (UAM), se identificaron comunidades sensibles de vegetación en torno al campamento español en praderas vírgenes de la Península Byers (ASPA 126), Isla Livingston, susceptibles por tanto de sufrir un impacto acumulado por pisoteo por parte de las expediciones de investigadores. Con los permisos requeridos se realizó una estancia de veinte días en el ASPA para realizar los trabajos planteados. Para el diseño experimental se toman como referencia los trabajos metodológicos de Cole 1995a, 1995b que marcan un método sencillo de testado de indicadores y definición de estados a través de una simulación de impacto experimental. Los indicadores seleccionados han sido depurados en estudios previos sobre suelos antárticos, iniciados por Tejedo (2005, 2009, 2013), a los que se añaden indicadores clásicos propios de la vegetación (tales como cobertura y biomasa). Los distintos niveles de presión son emulados de forma experimental y contrastados frente a niveles reales (grupos científicos o carga de visitantes en sitios de visita). Asimismo con este estudio se busca evaluar las estrategias de respuesta para las distintas presiones y fuerzas conductoras (turismo e investigación). Para la medición final de algunos parámetros se tomaron muestras que posteriormente fueron analizadas en los laboratorios del dpto. de Ecología de la UAM. A su vez las especies constituyentes fueron determinadas por el Dr. Lara en los laboratorios del dpto. de Botánica de la UAM. Adicionalmente en las campañas 2010-11 y 2011-12 estos indicadores se aplicaron de manera práctica para comparar y monitorizar el estado de las extensas praderas del sitio de visita Isla Barrientos.

Investigación II. Riesgo ambiental de la expansión de una especie no nativa. El segundo capítulo se centra en una de las mayores amenazas para la biodiversidad en la Antártida, la introducción de especies asociada a la presencia humana. La investigación surge tras identificar en colaboración con el Dr. Hughes (BAS) una especie no-nativa que permaneció con un largo periodo sin ser monitorizada. Esta especie estaba presente en un enclave al que podemos tener la oportunidad de acceso en la campaña 2011-12 gracias al desarrollo de otros trabajos del programa nacional español en la zona y el apoyo del personal de la cercana Base Argentina Primavera donde se realizó una breve estancia. Así se realiza un seguimiento descriptivo a la *Poa pratensis* valiéndose como modelo de enfoque referencial las directrices de Evaluación de Riesgo Ambiental (ERA) desarrollados por la US-EPA (1998). Como marco de referencia en el panorama antártico los trabajos de Hughes & Convey (2010, 2012) revisan los protocolos existentes de evaluación especies no nativas. Para identificar la planta contamos con el trabajo de Corte (1956) que define las propiedades de la variedad de Poa pratensis introducida así como los lugares originales de inserción. El presente estudio busca evaluar esta amenaza presente y futura a través de la descriptiva del estado de una planta no nativa de largo periodo así como la construcción de escenarios para valorar alternativas respuesta.

Investigación 3. Monitoreo de los niveles de CORT en colonias de pingüino El presente capítulo desarrollado en conjunto con el Dr. Barbosa (MCNM) busca validar una técnica novedosa para el estudio de las perturbaciones a la fauna antártica por presencia humana. Se trata de la medición de la hormona corticosterona (CORT) acumulada en las plumas crecientes durante la muda. Los estudios de control de Bortolloti (2008, 2009) definen la aproximación metodológica a la medición de los niveles de estrés a través de mediciones en pluma en las especies Barbijo, Papúa y Adelia. Asimismo en estudios previos se ha relacionado los niveles medidos en colonias de pingüino Papúa con alteraciones potencialmente provocadas por presencia humana (Barbosa et al. 2013). De esta manera la presencia humana continuada es una fuerza conductora susceptible de generar un efecto en los niveles de hormona de las aves, afectando al estado de salud de las aves que podría ser monitorizado.

La ejecución del presente estudio fue posible gracias al grupo de investigación Pinguclim, dirigido por el Dr. Barbosa. que llevó a cabo una recolección de muestras de pluma en animales brevemente capturados para otros estudios y por tanto obteniendo muestras de individuos caracterizados en distintas colonias. Esto nos permite realizar un diseño comparativo entre espacios con distinto grado de presencia humana. Así no fue necesario generar ningún impacto adicional. Las muestras facilitadas han sido tratadas y analizadas en colaboración con la Dra. Lauzurica, en los laboratorios del ISCII. Posteriormente los datos han sido analizados estadísticamente en colaboración con la Dra. Justel, del departamento de Matemáticas de la UAM y el Dr. Barbosa. No se ha elaborado ninguna propuesta concreta de gestión más allá de la discusión de resultados, dado que la investigación se centra en definir el estado de las colonias antes que en la cuantificación de impactos. Esta técnica aplicada sobre plumas de pingüinos ya recogidas en el suelo tras la muda busca ofrecer a medio plazo un registro de los niveles basales promedio de la hormona del estrés dominante en las aves limitando el contacto con los animales como mecanismo de monitoreo ambiental. Pero para ello es necesario primero llevar a cabo una validación. Asimismo en el presente momento el indicador sigue en fase de desarrollo y validación, actualmente testando plumas recogidas del suelo (datos aún en fase de muestreo y análisis, véase discusión).

Investigación 4. Análisis del repositorio E.I.E.S. Los capítulos previos se centran en el estudio del comportamiento de los sistemas terrestres ante distintos impactos y amenazas. Además es igualmente necesario conocer información precisa sobre las presiones que generan toda esa serie de impactos. La presente investigación estudia la carga de presión ene áreas protegidas a través de un diseño de seguimiento de la información disponible sobre la presencia de científicos a lo largo de tres campañas antárticas (2008-09/10-11). Esto fue posible gracias a la realización de una estancia breve de investigación en el British Antarctic Survey (BAS). Los estudios sobre la carga de presión científica se realizaron a través de la recopilación y análisis de los datos obtenidos a partir de los informes anuales de los programas nacionales en el repositorio EIES de la ATS (2012). Este repositorio contiene toda la información aportada por los programas nacionales de investigación sobre el desarrollo de sus campañas. Complementariamente los 71 planes de gestión de ASPAs han sido revisados de forma sistemática extrayendo toda la información relevante a la extensión de las ASPA y los valores contenidos en una base de datos para su posterior análisis y evaluación. A partir de los informes se construyó una base de datos sobre la que se generaron indicadores de carga de presión, tales como la huella humana en forma investigadores por kilometro cuadrado de suelo libre de hielo o la internacionalidad de los ASPAs en forma de países visitantes del espacio. Igualmente se elaboraron indicadores de cumplimiento del propio sistema en forma de informes anuales aportados por el conjunto de países constitutivos de pleno derecho.

Investigación 5. E.I.A. de las actividades científicas en un ASPA Una vez conocida la presión global en la red de áreas protegidas cabe preguntarse en detalle el impacto global que supone la investigación científica en un área protegida dada. Como modelo de referencia se toman las directrices de evaluación de impacto ambiental (EIA) en la Antártida (ATCM 2005 WP 226) referido al artículo 3º del Protocolo Medioambiental (1998). Esta investigación ha podido ser abordada a través de un diseño de seguimiento a un caso real mediante la recopilación de información en el campamento científico español en la Península Byers durante su periodo de funcionamiento (2000-10). A partir de la información sobre la carga de presión anual se cuantifican los costes globales e impactos locales asociados a la investigación (identificados por Tin et al. 2009) así como los beneficios generados. La cuantificación de emisiones de

CO_2 sirve como primer indicador ya que establece un parámetro comparativo de los costes de esta actividad, así este estudio se basa en el trabajo de Farreny (2010) y permite ser comparado a los costes de las actividades turísticas. Por su parte las conclusiones experimentales sobre la gestión del pisoteo (capítulo 4.1) son evaluadas sobre un caso real, cuantificando la carga de pisoteo existente a lo largo del periodo de diez años a través de los diarios de los investigadores. A partir de estos datos se realizó una evaluación de la red de ocupación en el ASPA pudiendo ser evaluarla en consonancia con las estrategias pertinentes determinadas por Tejedo et al. (2009, 2013). Finalmente se cuantifica el valor científico del ASPA a través de la producción científica (véase en relación Benayas et al. 2013 y el apartado de discusión de esta tesis).

Investigación 6. Aplicación del modelo M.E.A. para el estudio de un ASMA El presente capitulo evalúa los escenarios de futuro en la isla a través de la metodología de los Ecosistemas del Milenio (MEA 2005). Este diseño tiene como finalidad una simulación de condiciones de un sistema para evaluar las estrategias de actuación (Mooney et al. 2004). La mayor ventaja que encuentra es el tratamiento de los problemas a nivel de ecosistema para la conservación frente a métodos específicos (Sutherland et al. 2012). Para conformar los escenarios se revisa el desarrollo histórico del ASMA, los agentes de cambio regionales, las previsiones de futuro sobre actividades locales y las alternativas de actuación en la isla. Con ello se plantean distintos escenarios de futuro siguiendo una escala de protección. Esta a su vez se contrasta con una escala de aceptación de los grupos interesados. En base a estas dos premisas se evalúa la efectividad de las distintas alternativas de actuación de los distintos escenarios propuestos. Finalmente se contrastan las alternativas para formular una estrategia de gestión global.

3.3 ÉTICA EN LA INVESTIGACIÓN Y TOMA DE MUESTRAS

Las investigaciones de la tesis doctoral basan, al menos parcialmente, su diseño en la descriptiva, seguimiento y comparativa de sitios con inspecciones en campo, toma de muestras y desarrollo de experimentos con presencia directa. La investigación se ha realizado con las consideraciones éticas propias de un estudio cuya finalidad es la propia conservación. La toma de muestras y acceso a áreas protegidas ha sido realizada a través de permisos otorgados por la autoridad polar nacional, en este caso el Comité Polar Español (CPE). No se incluyen otras muestras tomadas simultáneamente para estudios en los que se ha participado (tales como muestreos de fauna edáfica o catálogos de especies vegetales en otros espacios) pero cuyos objetivos no se encuentran directamente relacionados con los objetivos específicos de la presente tesis doctoral. No obstante son comentados en la discusión al tratarse de aspectos complementarios relevantes para los estudios de conservación. Respecto a los costes ambientales de la toma de muestras se ha estimado que las comunidades potencialmente afectadas localmente por la propia investigación quedan muy por debajo del 1 % de su dimensión total y por ello asumimos que el impacto es siempre menor o transitorio. Al finalizar las campañas se ha realizado una evaluación ambiental de actividades y los datos y metadatos obtenidos han sido compartidos en los repositorios de intercambio de información, en este caso gracias al Centro Nacional de Datos Polares. Asimismo se ha buscado optimizar los beneficios frente a los costes, en primer lugar combinando los objetivos de los trabajos de conservación con otros estudios regionales de grupos investigadores colaboradores (fundamentalmente estudios limnológicos, botánicos y faunísticos), en segundo lugar omitiendo investigaciones potencialmente dañinas o innecesarias (reduciendo el uso de reactivos a conservantes naturales, evitando la duplicidad de muestras así como limitando las molestias a fauna) y reduciendo el número de investigadores al mínimo necesario (si bien esto ha podido limitar algunos trabajos), en tercer lugar generando resultados no dirigidos (por ejemplo: catálogos de especies, informes al Tratado Antártico) y en cuarto lugar buscando la mayor difusión de los resultados obtenidos en foros científicos y al público general. No obstante, la experiencia adquirida nos hace pensar que aún se puede optimizar todavía más la investigación futura, en particular analizando la relevancia de las investigaciones y seleccionando cuidadosamente los sitios de trabajo.

REFERENCIAS BIBLIOGRÁFICAS DEL CAPÍTULO

- ATCM (Antarctic Treaty Consultative Meeting) (2006). Practical biological indicators of human impacts in Antarctica. Information Paper No. 88. Presented by SCAR/COMNAP at XXIX ATCM, 12-26 Jun 2006. Edinburgh, United Kingdom.
- Bortolotti, G.R., Marchant, T.A. & Blas, J. (2008). Corticosterone in feathers is a long-term, integrated measure of avian stress physiology. *Functional Ecology*, 22: 494-500.
- Cole, D.N. (1995a). Experimental trampling of vegetation. I. Relationship between trampling intensity and vegetation response. *Journal of Applied Ecology*, 32: 203-214.
- Cole, D.N. (1995b). Experimental Trampling of Vegetation. II. Predictors of Resistance and Resilience. *Journal of Applied Ecology* 32: 215-224.
- Benayas, J. García D. Muñoz, M. & Tejedo, P. (2006) Análisis de la capacidad de acojida e ingresos generados por las actividades y equipamientos de Uso Público de la Red de Parques Nacionales. Organismo Autónomo de Parques Nacionales. Ministerio de Medio Ambiente.
- Benayas, J. Tejedo, P. García D. & Muñoz, M. (2007) Perspectivas actuales y retos de futuro en la gestión de actividades de Uso Público en la Naturaleza. En: Boada, M. & Benayas J. (coord.) Naturaleza y Uso Público: movilidad, impactos y propuestas. Fundación Abertis. Barcelona. pp. 37-48.
- Benayas J, Pertierra RL. Tejedo P. Bermudez O. Lara F. Hughes KA. & Quesada A. (2013). A review of scientific research trends within ASPA 126 Byers Peninsula, South Shetland Islands, Antarctica. *Antarctic Science,* doi:10.1017/S0954102012001058.
- EUROSTAT (1999). *Towards Environmental pressure Indicators for the EU*. Panorama of the European Union. 97 pp.
- Leung Y.F. & Marion, J.L. (2000) Recreation impacts and management in wilderness: A state of knowledge review. In Cole, D.N. McCool, S.F Borrie, W.T. & O'Loughlan J. (comps.) Wilderness science in a time of change conference - Volume 5: Wilderness ecosystems, threats and management. Proceedings RMRS-P15-Vol-5. pp. 23-48.
- Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and human well-being: synthesis. Island Press, Washington, D.C.
- Metcheva, R., Yurukova, L., Teodorova, S. & Nikolova, E. (2006). The penguin feathers as bioindicator of Antarctica environmental state. *Sci Total Environ*, 362: 259-65.
- Mooney H.A., Cropper A. & Reid W. (2004) The Millennium Ecosystem Assessment: What is it all about? *TRENDS in Ecology and Evolution* Vol.19 (5): 221 – 224
- Noss, R. (1999). Assessing and monitoring forest biodiversity: A suggested framework and indicators. *Forest Ecology and Management*, 115: 135-146.
- Hammitt, W.E. & Cole, D.N. (1998) Wildland Recreation: Ecology and Management (2nd ed.) New York, NY: John Wiley & Sons.
- Hassan, R., Scholes, R. & Ash, N. (eds.) (2005). *Ecosystems and Human Well-being: Current State and Trends*. Millennium Ecosystem Assessment (Program). Condition and Trends Working Group. Island Press. Washington DC. 917 pp.

- Hockings, M., Stolton, S., Leverington, F., Dudley, N. & Corrau, J. (2006). *Evaluating Effectiveness: a framework for Assessing Management Effectiveness of Protected Areas 2nd edition*. International Union for the Conservation of Nature World Commission on Protected Areas, Gland, Switzerland.
- Hughes, K.A. & Convey, P. 2010. The protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. *Global Environmental Change,* **20**, 96-112.
- OECD (Organisation for Economic Co-operation and Development) (1993). *OECD core set of indicators for environmental performance reviews. A synthesis report by the Group on the State of the Environment*. Environment monographs, n° 83. OCDE/GD(93)179. 39 pp.
- Pintér, P., Ardí, P. & Bartelmus, P. (2005). *Indicators of Sustainable Development: Proposals for a Way Forward*. Expert Group Meeting on Indicators of Sustainable Development United Nations Division for Sustainable Development.
- Sutherland, W.J., Adams, W.M., Aronson, R.B., Aveling, R., Blackburn, T.M., Broad, S., Ceballos, G., Cote, I.M., Cowling, R.M., Da Fonseca, G.A.B., Dinerstein, E., Ferraro, P.J., Fleishman, E., Gascon, C., Hunter, M., Hutton, J., Kareiva, P., Kuria, A., MacDonald, D.W., MacKinnon, K., Madgwick, F.J., Mascia, M.B., McNeely, J., Milner-Gulland, E.J., Moon, S., Morley, C.G., Nelson, S., Osborn, D., Pai, M., Parsons, E.C.M., Peck, L.S., Possingham, H., Prior, S.V., Pullin, A.S., Rands, M.R.W., Ranganathan, J., Redford, K.H., Rodriguez, J.P., Seymour, F., Sobel, J., Sodhi, N.S., Stott, A., Vance-Borland, K. and Watkinson, A.R. (2009) One Hundred Questions of Importance to the Conservation of Global Biological Diversity. Conservation Biology 23(3), 557-567.
- Smetacek, V. and Nicol, S. (2005) Polar ocean ecosystems in a changing world. Nature 437(7057), 362-368.
- Tejedo, P., Justel, A., Rico, E.,. Benayas, J., & Quesada, A 2005. Measuring impacts on soils by human activity in an Antarctic Special 803 Protected Area. *Terra Antarctica Reports*, **12**, 57–62.
- Tejedo, P., Justel, A., Benayas, J., Rico, E., Convey, P. & Quesada, A. 2009. Soil trampling in an Antarctic Specially Protected Area: tools to assess levels of human impact. *Antarctic Science*, **21**, 229–236.
- Tejedo P. (2012) Seguimiento y Control de Impactos Recreativos en Senderos en Espacios Naturales Protegidos. Aplicación en Senderos Turisticos Antárticos. Tesis Doctoral, UAM. Segovia, Enero 2012.
- Tejedo P. Pertierra RL. Benayas J. Justel A. Quesada A. & Convey P. (2012) Trampling on Maritime Antarctica. Can soil ecosystems be effectively protected through existing codes of conduct? *Polar Research*
- U.S. EPA. Guidelines for Ecological Risk Assessment. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, DC, EPA/630/R095/002F, 1998

Capítulo

4 Resultados

4.1 Procesos rápidos de denudación en comunidades criptógamas de la Antártida Marítima sometidos al pisoteo humano

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Resumen Este estudio explora el impacto del pisoteo generado por personas en comunidades dominadas por musgos y líquenes de la Antártida Marítima. Se llevó a cabo una simulación de pisoteo experimental en parcelas no afectadas previamente, caracterizadas por diferentes composiciones de plantas criptógamas terrícolas en la Península Byers. Las comunidades estudiadas fueron 1) una alfombra uniforme de musgos, 2) una pradera heterogénea compuesta de mogotes y céspedes, y 3) una comunidad liquenica en páramos. Todas las comunidades analizadas fueron extremadamente sensibles pero con distintos procesos de denudación observados. Ninguna de las parcelas mantuvo el 50% de la cobertura inicial tras 200 pasadas. Incluso muy bajas intensidades de pisoteo provocaron una perturbación en todas las parcelas. Las sensibilidades de las distintas comunidades fueron identificadas con objeto de formular recomendaciones para minimizar los impactos del pisoteo. En nuestro estudio la comunidad dominada por líquenes en suelos secos y expuestos mostró la mayor sensibilidad al pisoteo. En el caso de las comunidades de musgos, la resistencia fue menor en los suelos turbosos con mayor cantidad de biomasa y agua. Con la tendencia actual de creciente presencia humana en la Antártida pronosticamos que los impactos acumulativos del pisoteo en las décadas futuras afectaran muy negativamente a las comunidades de musgos y líquenes terrícolas.

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Rapid denudation processes in cryptogamic communities from Maritime Antarctica subjected to human trampling

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Abstract: This study explores the impact of human trampling on moss and lichen dominated communities of Maritime Antarctica. A simulation of trampling was performed on previously unaffected plots of different terricolous cryptogamic assemblages at Byers Peninsula, Livingston Island. The communities studied were: 1) a uniform moss carpet, 2) a heterogeneous moss assemblage composed of hummocks and turfs, and 3) a fellfield lichen community. All communities analysed were extremely sensitive but different denudation processes were observed. None of the plots maintained 50% of initial coverage after 200 pedestrian transits. Even very low trampling intensity resulted in disturbance at all plots. Sensitivities of the different communities were identified in order to formulate recommendations for minimizing the trampling impacts. In our study the lichen dominated community on dry exposed soils exhibited the lowest resistance to trampling. For moss communities, lower resistance was lower found in peat soils with higher water content and biomass. With the current trend of increasing human presence in Antarctica, we predict that the cumulative impacts of trampling over future decades will adversely affect all types of moss and lichen communities.

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Key words: fellfield soils, human impact, management, moss and lichen communities, recreation ecology, trampling simulation

Introduction

Bryophyte and lichen communities constitute one of the few types of terricolous vegetation in Maritime Antarctica, being especially developed in favourable coastal locations. Ice-free areas of coastal sites experience most of the human impact from ship-borne tourism and scientific research on the Antarctic Peninsula and offshore islands (Lynch *et al*. 2010, Hughes *et al*. 2011). Therefore terrestrial vegetation is especially vulnerable to human foot traffic. The increase of visitors to the Antarctic has been exponential during the last twenty years with cumulative trampling impacts detected at or near tourist landing sites (Bastmeijer & Roura 2004) and around scientific field camps (Tejedo *et al*. 2009). Increased human presence is relatively well documented. Data on national research programmes activities are available on the Antarctic Treaty Secretariat (ATS) website (http://www.ats.aq/e/ie.htm). Information on tourist visits is published on the International Association of Antarctica Tour Operators (IAATO) website (http://iaato.org/es/tourism-statistics). Tourist visits are largely concentrated in the Antarctic Peninsula region. Tourists arrive on cruise ships and make shore visits on the ice-free coastal zones of two to three hours each, one to three times daily (Bertram 2007). Scientific expeditions are far more widespread along the Antarctic Peninsula, as personnel can work out of stations, ships or field camps (Hughes *et al*. 2011). As a result, both diffuse and concentrated trampling patterns can be expected to result from human activities on the Antarctic Peninsula.

Other factors, such as climate change (Vaughan *et al*. 2003, Turner *et al*. 2005) and human induced biological invasions (Frenot *et al*. 2005, Hughes & Convey 2010), could act in synergy with the deterioration of terrestrial ecosystems resulting from trampling (Smith 1994, Olech 1996, Smith & Richardson 2011). Moreover, other human activities could also have indirect effects. For example, in the case of the South Orkney Islands, sealing activities in the 18th century may have indirectly led to the severe damage to vegetation caused by expanding fur seal populations (Smith 1988). Available knowledge on the effects of trampling in the Antarctic is currently rather sparse (Tin *et al*. 2009, Convey 2010).

This study offers a first attempt to assess the sensitivity of bryophyte and lichen terricolous communities under experimental trampling conditions in Antarctica. Previous studies of trampling on bare soils conducted by Ayres *et al*. (2008) in the McMurdo Dry Valleys showed that even low levels of human traffic could produce impacts on soil biota. Tejedo *et al*. (2005, 2009) developed indicators and measured the effects of experimental trampling on bare soils on Byers Peninsula. On Cuverville Island, de Leeuw (1994) and Beyer & Bolter (2002) reported that low trampling intensities rapidly led to disturbances to terrestrial vegetation. Thor (1997) and Johansson & Thor (2008) studied the possible impacts of human activities on terrestrial vegetation around

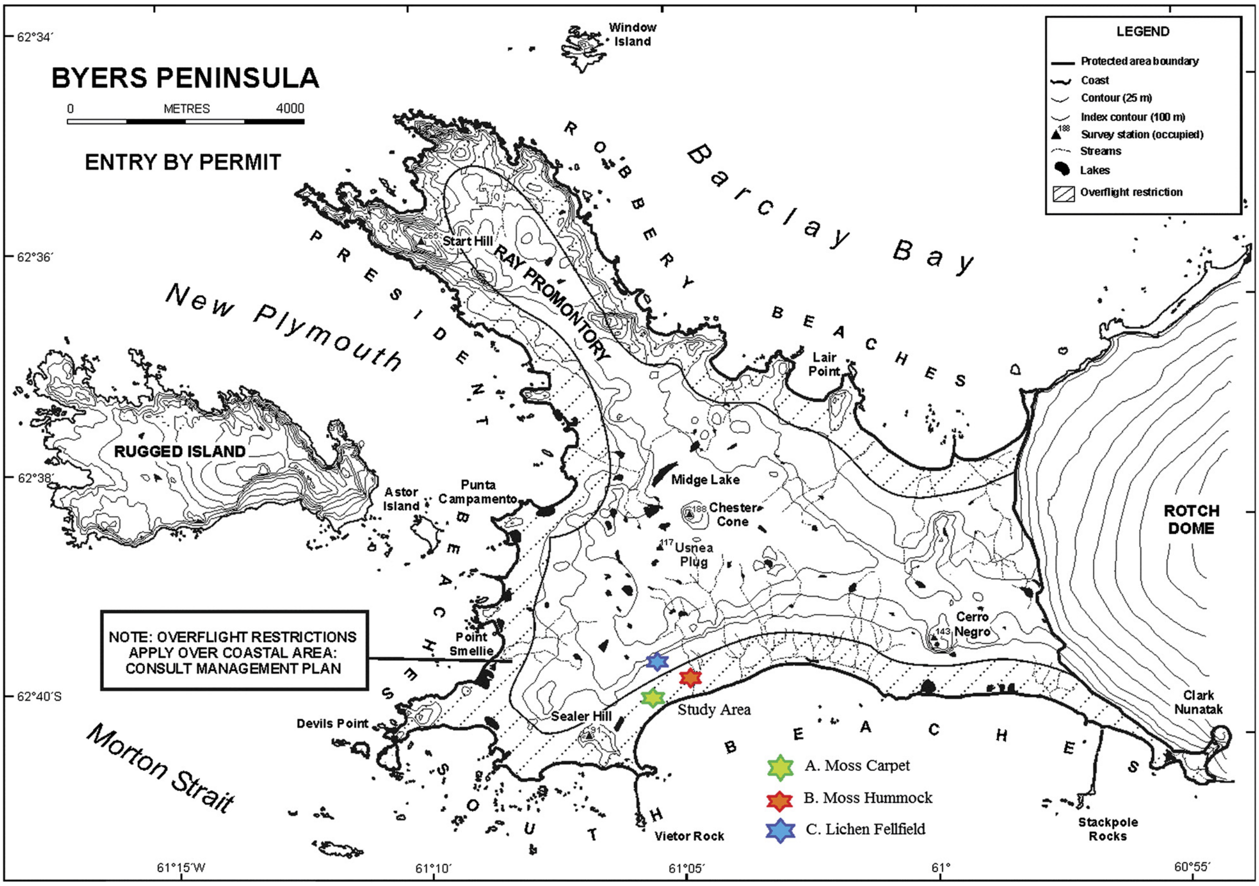

Fig. 1. Study site at Byers Peninsula ASPA No. 126 topographic map (modified). Inset: the location of the three cryptogamic communities in the South Beaches of Byers Peninsula. Source: ASPA 126 Management Plan, Byers Peninsula (Map 2).

research stations in Dronning Maud Land and reported no severe damage but a decline in the number of lichen species. In our study area, the South Shetland Islands, significant damage to terrestrial vegetation has already been documented at sites with a high concentration of scientific stations, such Fildes Peninsula, King George Island (ASOC 2004), or tourist visited sites such Barrientos Island, Aitcho Archipelago (Ecuador & Spain 2012). On a larger scale, Scott & Kirkpatrick (1994) conducted studies of the effects of trampling on the biodiversity of sub-Antarctic Macquarie Island. Also in the sub-Antarctic, Gremmen *et al*. (2003) examined the different habitats crossed by paths on Marion Island. In the Arctic, West & Maxted (2000) examined the effects of trampling around field camps in Svalbard. To our knowledge, no experimental trampling studies focused on the sensitivity of cryptogamic formations have been performed in the Antarctic Peninsula.

Experimental trampling studies of vegetation have been frequently conducted in more temperate areas (Cole & Bayfield 1993, Cole 1995a, 1995b, Marion & Cole 1996, Marion & Leung 2001, Farrell & Marion 2001, 2002), providing an extensive framework of procedures. The specific aim of the current study is to measure the resistance capacity of different Antarctic terricolous cryptogamic communities to human trampling. The resistance of vegetation to trampling is defined by the amount of damage in terms of cover loss caused by a given trampling intensity (Cole & Bayfield 1993). To this end, we used a linked set of indicators and field observations. Our objectives were to identify effective indicators for assessing the consequences of trampling on cryptogamic vegetation, and to estimate the magnitude of this impact on different bryophyte and lichen communities. With this study, we hope to advance our baseline knowledge on crytogamic formations in the Antarctic Peninsula, contribute towards minimizing the environmental impacts of scientific expeditions and alert the scientific community to the challenges faced by these most sensitive plant formations in the context of increased human activity in the Antarctic.

Material and methods

Description of the study area

Byers Peninsula is situated on the western side of Livingston Island (62°34'35"–62°40'35"S, 60°54'14"–61°13'07"W and is

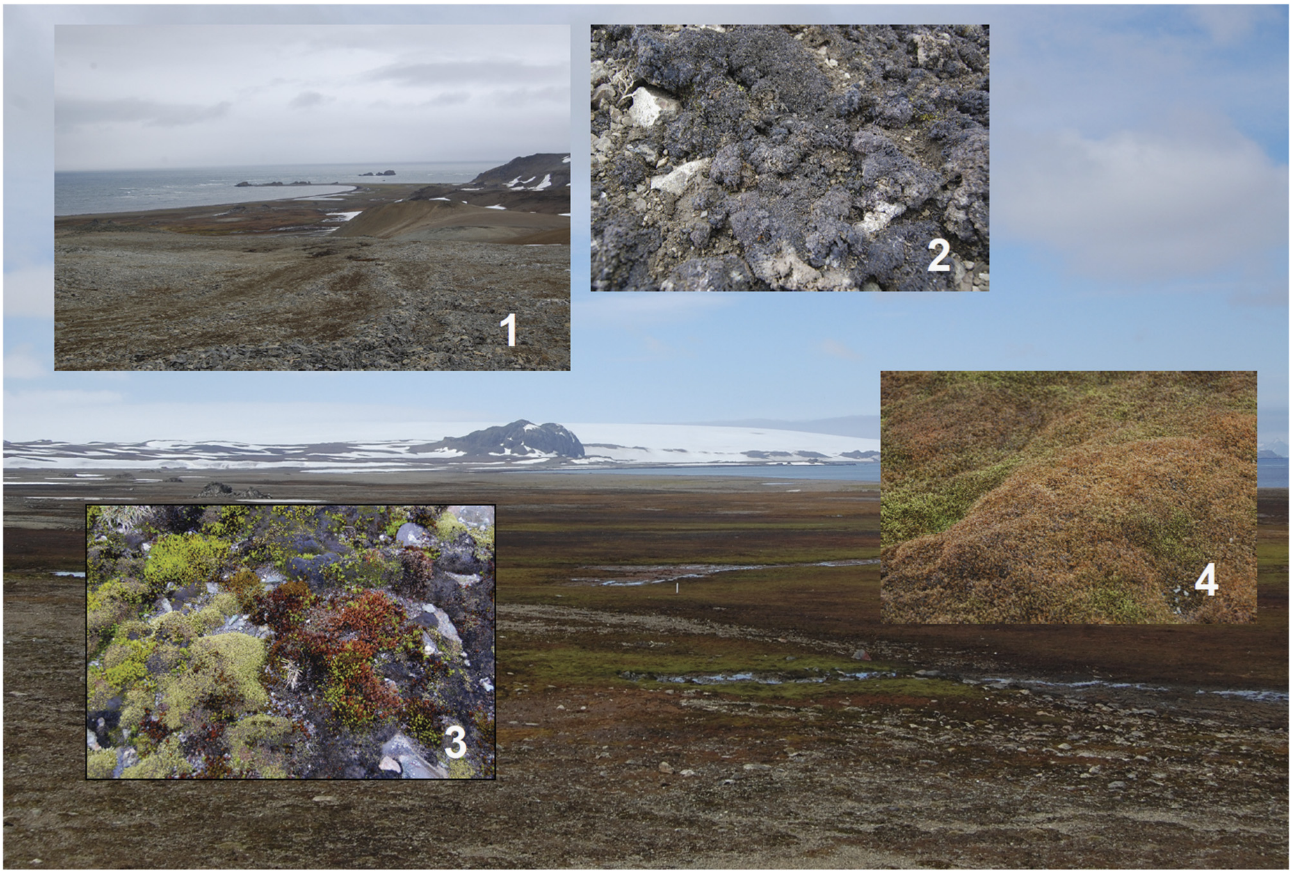

Fig. 2. Diagram of cryptogamic communities in South Beaches. Front image: large moss covered lowland area containing communities A and B. Author: L. Pertierra. January 2010. Top left-hand image (1): highland containing community C. Top right-hand image (2): detail of fellfield lichen community (C) on exposed upland slopes. Bottom left-hand image (3): detail of a moss hummock community (B) on a raised beach terrace. Bottom right-hand image (4): detail of a uniform moss carpet community (A) on a coastal plane.

the largest ice-free area in the South Shetland Islands (López-Martinez *et al.* 1996). Its numerous fresh-water bodies are of interest for limnological studies (Quesada *et al.* 2009). The periglacial landscape comprises tens of lakes and streams with diverse biological conditions (Toro *et al.* 2007). The landforms and deposits with various origins support varied types of vegetation. The cryptogamic flora of Byers Peninsula is remarkably rich, including 42 species of mosses (Ochyra *et al.* 2008, ATCM 2011), similar to that of South Bay, another important ice-free area on Livingston Island (Sancho *et al.* 1999).

Although lichen communities can be found throughout Byers Peninsula, bryophyte vegetation is more developed on the south coast (Lindsay 1971), and especially in areas at low altitudes that benefit from nearby meltwater. We analysed three terricolous cryptogamic communities situated inland and on the southern beaches (Fig. 1) which have different appearances and ecological affinities (Fig. 2). Community A (“moss carpet community”) comprises uniform moss carpets of highly hydrophilous pleurocarpous mosses growing on wet coastal plains, permanently bathed by melting snowpacks. Community B (“moss hummock community”) corresponds to heterogeneous moss assemblages dominated by large hummocks of pleurocarpous mosses, irregularly patched with turfs and cushions of acrocarpous mosses, developed on seepages areas of raised beach terraces not permanently wetted. Community C (“lichen fellfield community”) is an example of a fellfield cryptogamic community dominated by small foliose lichens accompanied by different mosses, growing on seepage areas of exposed upland slopes that dry out after the spring melt. Following the classification by Smith (1996) and Ochyra *et al.* (2008) the three Q1 communities can be related to three different types of sub-formations within the non-vascular cryptogam tundra formation. Community A corresponds to the bryophyte carpet and mat sub-formation. Community B the tall moss cushion (hummock) sub-formation, whereas community C is placed in the crustaceous and foliaceous lichen sub-formation.

Determination of baseline conditions

At the start of each experiment, before any trampling has been initiated, the baseline conditions of each cryptogam community were referred to as 'Level Zero' (0). In order to conduct initial descriptions of the bryophyte and lichen composition of each community, experimental plots of 6 m^2 that were representative of each community were selected. Species composition was determined in the laboratory from samples from the plots, following established procedures (Sancho *et al*. 1999, Bednarek-Ochyra *et al*. 2000, Øvstedal & Smith 2001, Putzke & Pereira 2001, Ochyra *et al*. 2008). Specimens are stored in the MAUAM herbarium.

Edaphic parameters were determined in the laboratory from triplicate core samples of each community. Soil organic matter was quantified by the Walkley & Black wet oxidation method (Nelson & Sommers 1982). Total nitrogen (N) content was determined by the Kjeldahl method (Bremner & Mulvaney 1982). Exchangeable potassium (K) was determined by atomic absorption spectrometry using an ammonium acetate extraction method (Thomas 1982). The method of Olsen *et al*. (1954) was used to estimate available phosphorus (P). Soil acidity (pH) was measured in water and in 0.1 M potassium chloride (KCl) using a 1:2.5 soil/solution ratio. Electrical conductivity was measured in a 1:5 soil: water extract. General geomorphological information was extracted from local cartography (López-Martinez *et al.* 1996, Navas *et al*. 2008).

Procedures for trampling experiments

Trampling was measured as the number of pedestrian transits. For the purpose of standardization (Cole 1995a, 1995b), experiments were performed by a person 1.80 m tall, weighing 85 kg and wearing rubber boots. Transects followed the dimensions suggested by Cole & Bayfield (1993). Dimensions of 6 m x 1 m were selected in order that three random plots, each 25 cm x 25 cm, could be sampled at each of five semi-quantitative stages. The five sampling stages were defined by the resistance of the cryptogam communities to trampling. The first sampling stage took place when the first evidence of damage as a result of trampling could be seen, or when 95% of the vegetation cover remained intact. This stage was labelled as Level One (1). Trampling would continue and measurements were made at subsequent levels of degradation including: Level Two (2), where *c*. 75% of the vegetation cover remained intact, Level Three (3), where *c*. 50% of the vegetation cover remained intact, Level Four (4), where *c*. 25% of the vegetation cover remained intact and Level Five (5), where less than 5% of the initial vegetation cover remained intact. This approach was selected in order to fully cover the dynamics of vegetation denudation. Since it represents 50% of vegetation denudation, 'Level Three' serves as an indicator of resistance of the moss and lichen communities that can be used for comparing with other studies. In the remainder of this paper, we will refer to the various states of the cryptogam communities by means of a code combining the letter of the community (A-B-C) with the level of degradation (0 to 5).

For the purpose of monitoring when the next sampling stage was reached, the amount of vegetation cover was estimated every time trampling intensity was doubled. A grid of 25 squares was laid over a random plot of 5 cm x 5 cm and photographically documented. The percentage of area with complete loss of macroscopic structure was estimated and used as a measure of the loss of vegetation cover. Trampling intensity was increased until total disruption of the crytogamic community was reached.

At each sampling stage, physical and biological indicators were measured in three random 25 cm x 25 cm sampling plots. Soil resistance to penetration was used as an indicator of the effective gradual impact on soil compaction (Tejedo *et al*. 2005, 2009). Five measurements were taken at each sampling stage on the soil of each cryptogam community with a hand edaphic penetrometer. For total biomass and water content, core samples were removed from the sampling plots. In total, 54 circular cores were collected. Core dimensions (7 cm diameter x 7 cm length) were sufficient to obtain approximately 200 g of wet samples. A core depth of 7 cm was selected in order that all biomass could be recovered after trampling. As a result, the measured biomass and water content need to be considered at these conditions. Soil fraction from additional samples was sieved in a 2 mm mesh to measure soil moisture. Cores collected were frozen at -20°C in sealed bags until analysis.

Soil moisture, water content and total organic matter were respectively quantified in triplicates through loss-on-ignition technique with Wet & Dry Weight calculation after heating in porcelain crucibles in a muffle furnace. Soil moisture (% soil weight) and water content (% sample weight)

Table I. Chemical properties and nutrient content of the terrestrial cryptogamic communities from Byers Peninsula

Community	*n*	O.M. (%)		N (%)		C/N		K+ (cmol+/Kg)		P (ppm)		pH (1:2,5)		Electric Conductivity (dS/m)	
		Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
A. Moss Carpet	3	1.70	1.21	0.14	0.08	11.53	2.87	0.66	0.19	1.22	0.23	6.33	0.26	0.05	0.00
B. Moss Hummock	3	1.60	0.62	0.15	0.06	12.24	0.97	0.61	0.08	1.27	0.99	6.06	0.16	0.07	0.04
C. Lichen Fellfield	3	2.53	0.90	0.23	0.07	10.98	1.58	0.35	0.03	0.43	0.18	6.99	0.98	0.22	0.06

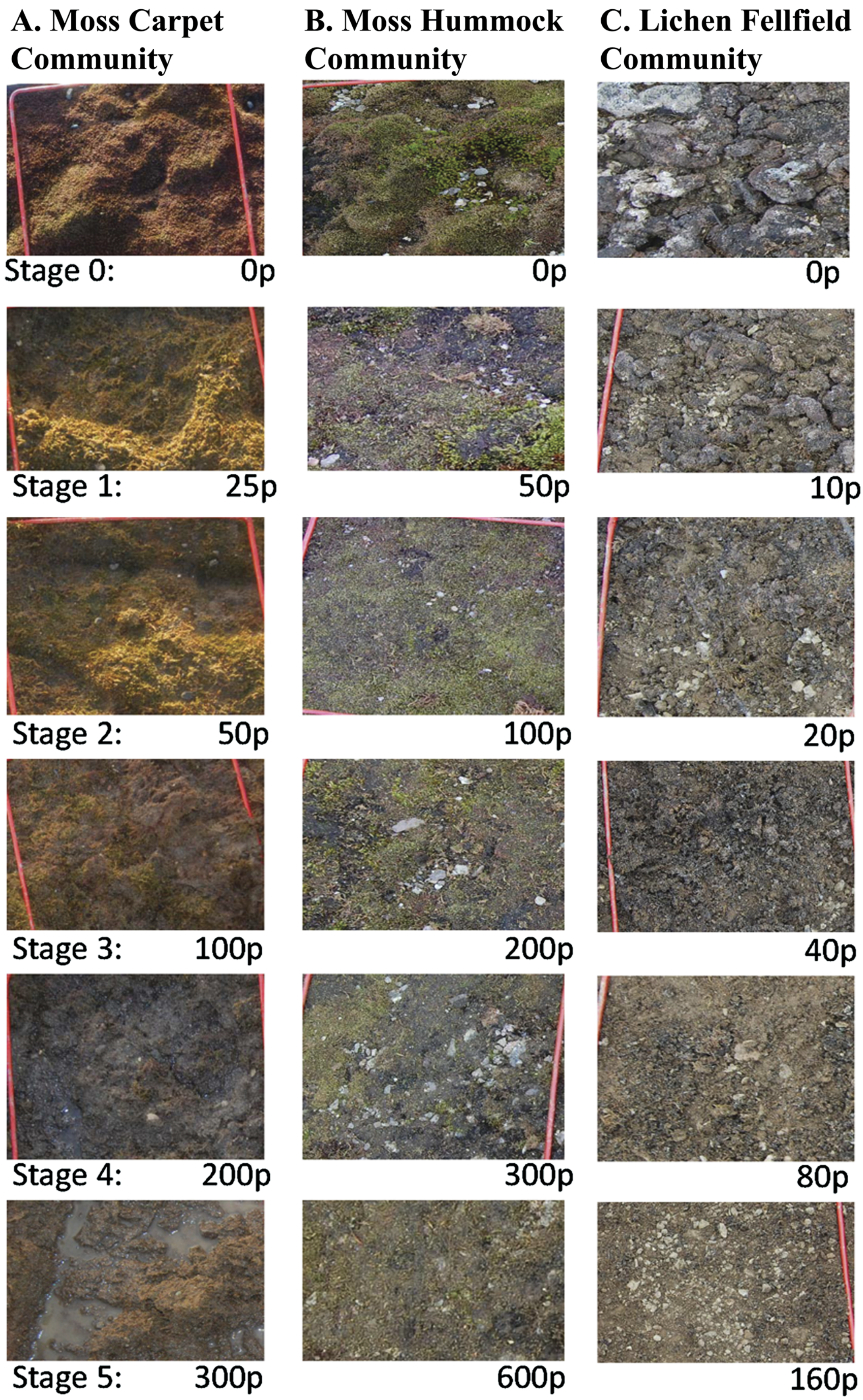

Fig. 3. Visual features. Visual status of experimental plots along trampling simulation respectively in A-B-C communities. Author: L. Pertierra. January 2010.

were measured after 24 hr at 105°C, while biomass (mg carbon (C) cm^{-2} soil) was measured after 4 hr at 450°C.

Results from soil resistance to penetration, water content and total biomass were expressed with standard deviations and represented in graphs. On these graphs the model fit which best represented the observed trend was also calculated with its coefficient of determination (r^2). Vegetation coverage loss trends were also represented. It was estimated once per stage and thus no standard deviations were obtained.

Experiments were conducted in the late summer on days where there had been minimal precipitation on previous days. Results on soil resistance to penetration and water content are circumscribed within these conditions and cannot be easily extrapolated to other studies. Nonetheless all measurements were performed on the three communities in parallel and they can therefore be compared.

Results

Floristic composition

Community A was made up of dense, uniform and extensive moss carpets that developed on flat terrain, and dominated by the hydrophilous pleurocarpous moss *Warnstorfia sarmentosa* (Wahlenb.) Hedenäs. Other large mosses could be occasionally found, particularly *Sanionia georgicouncinata* (Müll. Hal.) Ochyra & Hedenäs and *Polytrichastrum alpinum* (Hedw.) G.L. Sm. The community was heavily flooded, with a water content of 87% in core samples and a soil moisture content of 28% (see Supplemental Table at http://dx.doi.org/10.1017/S095410201200082X).

Community B comprised heterogeneous, moss dominated vegetation growing on sandy pebble-rich substrate of raised terraces, frequently adjacent to community A but under drier conditions. It was dominated by the pleurocarpous *Sanionia georgicouncinata* and, to a lesser extent, by the acrocarpous *Polytrichastrum alpinum*. Depending on microtopographical conditions, which favoured greater or lesser water supply, other species could be present, such as *Warnstorfia sarmentosa* or *Polytrichum juniperinum* Hedw. Intermixed with all these large mosses, many very small species could appear in small proportions, and we found *Bartramia patens* Brid., *Pohlia wahlenbergii* (F. Weber & D. Mohr) A.L. Andrews, *Andreaea regularis* Müll.Hal., *Brachythecium austrosalebrosum* (Müll.hal.) Kindb., and the leafy liverwort *Cephaloziella varians* (Gottsche) Steph. The Antarctic hairgrass *Deschampsia antarctica* E. Desv. was also present in small patches. Samples from this community had a water content of 53% and a soil moisture content of 19% (Supplemental Table). The substrate was sandier, resulting in moderate drainage, and bedrock was more evident and was occasionally visible.

Community C was a cryptogam assemblage that developed on upland terrains and was dominated by the blackish foliose cyanolichen *Leptogium puberulum* Hue. The pleurocarpous mosses *Brachythecium subpilosum* (Hook. f. & Wilson) A. Jaeger and *Sanionia uncinata* (Hedw.) Loeske were also abundant. Other mosses found in lower proportions were *Bartramia patens*, *Polytrichastrum alpinum*, *Schistidium lewis-smithii* Ochyra, and *Pohlia cruda* (Hedw.) Lindb. This community grew on moraine soils which were among the driest conditions included in this study. Water content in the samples was *c*. 21% and soil moisture was also around 20% (Table I).

Soil characteristics

Soil characteristics are shown in Table I. Organic matter (OM) content was very poor for the moss dominated communities A and B (mineralised soil), and was deficient in the lichen fellfield community C (soil mineral-organic). Results are consistent with the C/N ratios, which indicate that these nutrients do not act as constraints in the humidification–mineralization process. Nitrogen content is normal in Communities A and B, whereas it is comparatively high in Community C which probably has a higher mineral nitrogen ratio. Soils from all communities have a low salt content, and hence low electrical conductivity. All soils have very low values of phosphorus. Levels of potassium in all soils can also be considered as low but they lie within normal limits.

Physical effects of trampling

The effects of trampling on cryptogamic vegetation are influenced by several factors, such as hydrological conditions, geography and topography. These factors may influence the response of the plant communities to human activity. Visual effects of trampling experiments were

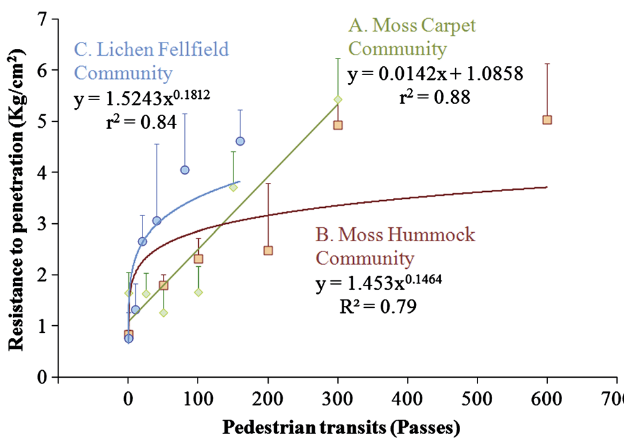

Fig. 4. Physical features. Trampling intensity (passes) and resistance to penetration (Kilograms per square centimetre) for trampling experiments at communities A, B and C.

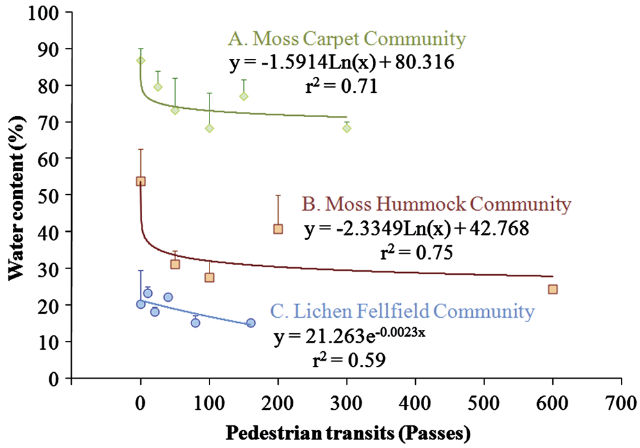

Fig. 5. Hydrological features. Trampling intensity (passes) and water content (percentage in weight) for trampling experiments at communities A, B and C.

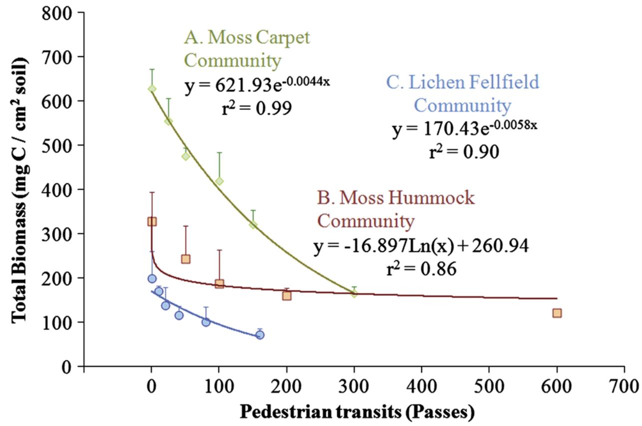

Fig. 7. *Biological features* (II). Trampling intensity (passes) and total biomass (milligrams per cm^2 soil) for trampling experiments at communities A, B and C.

photographically documented (Fig. 3). In the case of the moss carpet community (A), the first visible effects were detected after the first 25 passes (A1). Macroscopic destruction of the vegetation cover was detected after 300 passes (A5). The moss hummock community (B) exhibited visible effects after 50 passes (B1) and reached macroscopic destruction after 600 passes (B5). The lichen fellfield community (C) exhibited visible effects after only 10 passes (C1) and reached macroscopic destruction after only 160 passes (C5).

Soil characteristics differ between communities (Table I). Data obtained on resistance to penetration is shown in Fig. 4. Whereas initial values on soil compaction were similar (*c.* 1 kg cm^{-2}) for communities A, B and C, final values varied. Moss carpet community (A) soils' compaction reached *c.* 300 passes without saturation when the simulation ended due to the total loss of vegetation in the community. Moss hummock community (B) has an intermediate compaction on a slow rate up to 600 passes when the experiment finished. Finally, lichen fellfield community (C) has the fastest saturation at 160 passes with the lowest maximum compaction of the three communities at the end of the simulation.

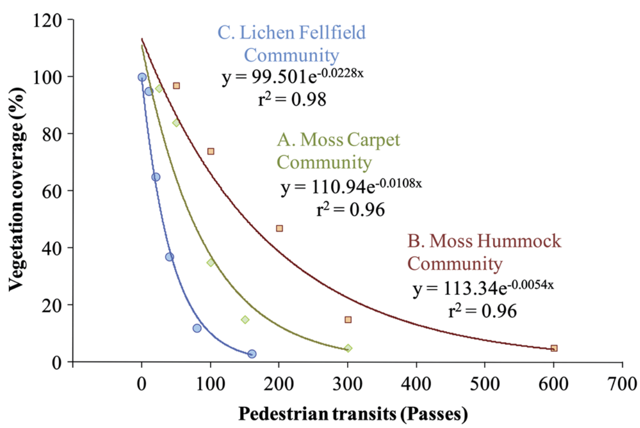

Fig. 6. Biological features (I). Trampling intensity (passes) and vegetation coverage (percentage) for trampling experiments at communities A, B and C.

The moss carpet community (A) was the richest in water content. It contained 87% water content prior to the experiment and at the end of the experiment, water content fell to 67% (Fig. 5). All of the three communities showed water loss as a result of trampling. Water content in the moss hummock community (B) dropped from an initial value of 55% to 26%. In the lichen fellfield community (C) water content fell from 24% to 18%.

Biological effects of trampling

Trends of biological parameters are shown in Figs 6 & 7. For all three communities, loss of vegetation coverage as a consequence of increased trampling followed a negative exponential model, although the variation rate was different for each community (Fig. 6). The lichen fellfield community (C) exhibited the fastest rate, whereas the moss hummock community (B) showed the lowest of the three.

The visual details of the denudation process were quite different for each community (Fig. 3). The moss carpet community (A) showed an initial resistance. During the first 10–15 passes, while footprints were visible, the structure of the community was apparently unaffected. At around 25 passes, first scars were observed and, as soon as the cohesion was damaged, the fissures advanced rapidly. Due to the high water content of this vegetation the fragmented portions formed a muddy mass. At *c.* 300 passes the muddy mass had become sufficiently eroded to reveal bare ground and allow puddles of water to form. Seventy-eight passes were sufficient to result in loss of 50% of the vegetation cover (Fig. 6).

The moss hummock community (B), growing on raised beach terraces, was drier and easier to walk on. The vegetation appeared to be firmer and exhibited a higher resistance than that of Community A. To disturb the cohesion required around 50 passes and scars were only produced in the bigger tufts which were more exposed. As trampling continued and, the vegetation was crushed instead of turning into a muddy mass as in the case of Community A. Loss of macroscopic moss coverage was not seen even up to 600 passes. One hundred forty seven passes were needed to cause a loss of 50% of the vegetation cover (Fig. 6).

Lichen fellfield community (C) was easily fractured with less than 10 passes, as the dominant lichen had a crunchy texture when dry. Total loss of plant cover was evident at 160 passes. Thirty-nine passes were sufficient to result in 50% loss of vegetation cover (Fig. 6).

Finally, total biomass per square centimetre of soil on experimental plots was quantified to contrast with plant coverage loss (Fig. 7). The moss carpet community (A) contained the highest initial biomass of 629 mg C cm^{-2}. Approximately 74% of the initial biomass was removed in the experimental process, leaving a final 165 mg C cm^{-2} soil at the end of the trampling experiment. The moss hummock community (B) had initially a 52% lower biomass content than in A. Biomass content in B was at 328 mg C cm^{-2} soil prior to trampling and was 121 mg C cm^{-2} soil after trampling, corresponding to a 63% loss. The lichen fellfield community (C) contained the lowest biomass content. It was slightly lower than in B (60%) and much lower than in A (31%). Biomass content in C began at 200 mg C cm^{-2} soil before trampling and ended at 72 mg C cm^{-2} soil after trampling, corresponding to a 68% biomass loss.

Discussion

Most of the mosses found in the samples from the three communities are common on Livingston Island (Sancho *et al*. 1999, Putzke & Pereira 2001, Ochyra *et al*. 2008), but two of them were reported for the first time for the island: *Pohlia wahlenbergii*, already known from other islands in the South Shetland Islands, and *Brachythecium subpilosum*, a new report for the archipelago (Lara & Pertierra in press). Both species have small known Antarctic populations (Ochyra *et al*. 2008). Liverworts are not well represented in Antarctica, and the tiny *Cephaloziella varians* is the most common and most widespread liverwort in Antarctica (Newsham 2010), and is abundant on Livingston Island (Sancho *et al*. 1999). The lichen *Leptogium puberulum* and the vascular plant *Deschampsia antarctica* one of the two phanerogams native to maritime Antarctic are representative components of the local flora (Lindsay 1971, Sancho *et al*. 1999). Communities that are richer in biodiversity are likely to harbour rare species, presumably with populations that are easily disturbed, although further studies will be needed before it could be determined if these populations are threatened.

Physical effects on soils

The pH ranges from slightly acidic (Communities A and B) to neutral (Community C), which is consistent with data obtained for this area by other authors (Navas *et al*. 2008). These results correspond to oligotrophic sand soils. Organic matter and electrical conductivity in Community C were found to be slightly higher than in the other two sites, but within the range of values quoted in previous studies (Roser *et al*. 1994).

Soil resistance to penetration proves to be a good indicator for assessing cumulative trampling effects in soils. It is noteworthy that, after the plant layer is pierced, the soil surface starts to act in the same way as bare soils (Fig. 3). The increase in penetration with increased trampling in Fig. 4 are similar to those found by Tejedo *et al*. (2009) for bare soil, and these values could in themselves be sufficient to disturb the existing edaphic fauna. Soil characteristics such as texture also differed among communities (Table I). Therefore the observed differences can be also explained by the physical properties of the soils of the different communities soils, such as bulk density (Tejedo *et al*. 2009). Our results show that drier areas with less dense vegetation were more sensitive to disturbance from trampling. The presence of vegetation presence prevented compaction by protecting the soil below.

In all three cryptogamic communities, water loss was consistently proportional to trampling (Fig. 5). We found that extreme conditions in water content affected negatively the plant resistances. As a result the moss hummock community (B) had in this case the highest resistance capacities. The moss carpet community (A) had the highest water content and hence exhibited the least resistance to trampling. In the lichen fellfield community (C), we also detected a diminished resistance that could be explained by the extreme dryness of the vegetation due to the particular environmental conditions that were present during the period of our experiments. For this reason it can be argued that resistance of the communities to trampling can be severely affected by meteorological conditions. Differences in resistance to penetration could be also linked to the initial water content of the community.

In contrast, soil moisture did not change much between communities nor along the transect (Supplemental Table), indicating that it was not affected by the trampling process. Long-term effects of trampling remain to be seen. Lower water retention due both to compaction increase and vegetation loss by trampling could lead to shifts in species composition. This projection can be exemplified by the results of Gremmen *et al.* (2003) who found significant differences in species composition and soil moisture between control plots and frequented paths on Marion Island.

Biological disturbances

Damages to vegetation are perhaps the most evident impacts from trampling (Fig. 3). The continuous and spongy moss carpets, rich in biomass and with a high water content, can absorb a small amount of disturbance. But, as soon as their initial capacity to resist disturbance is surpassed, the damage grows linearly with the amount of disturbance. Our results are similar to those of de Leeuw's (1994) obtained from moss peat vegetation on Cuverville Island, Danco Coast. In moss hummock communities the damage is gradual and is tempered by the physical characteristics of the community. Drier soils and strong attachment to the substrate could prevent moss from direct damage. These communities appear to be more resistant to trampling, but we must ascertain whether, when certain levels are surpassed, the damage becomes irreversible due to extreme loss of water availability or a thinner soil layer. Finally, lichen fellfield communities show a low degree of vegetation resistance to trampling due to its extreme dryness and the morphology of the dominant lichen with the mixed mosses, which are weakly attached to the substrate. Direct damage can be observed after a very small amount of disturbance.

Amount of vegetation cover and visual changes served as preliminary indicators for assessing degradation status and resistance capacity of cryptogamic communities in relation to different intensities of trampling (Figs 3 & 6). However, vegetation is frequently patchy and circumstantial disaggregation can be difficult to unequivocally distinguish from the effects of human trampling. If new species are found, it might be necessary to monitor small plots in order to assess the effects of disturbance on plant richness Thus, this indicator relies on the existing reference conditions (Fretwell *et al*. 2011). Alternatively the technique applied by Gremmen *et al*. (2003) involved comparing species composition along the path against composition on either side of it. That technique overcomes the need for long time series in sites without information on possible changes in species composition when assessing already impacted areas.

With the present results, i.e. 50% cover loss within less than 200 passes (Fig. 6), we consider all three communities as extremely sensitive to human trampling (Cole 1995a, 1995b, Farrell *et al.* 2001, 2002). Our results are similar to those of the most sensitive species described by Cole & Bayfield (1993), although their study was conducted on herbaceous vascular plants. While our trampling experiments may be indicating that these three cryptogamic communities in the Antarctic Peninsula have low short-term resistance to disturbance, it is possible that these communities possess high recovery capacities since cryptogams are characterized by their capacity for vegetative growth from fragmented units (Smith 1993, Johanson & Thor 2008).

Total biomass decreased as the amount of disturbance increased (Fig. 7). This was particularly evident in the case of Community A (moss carpet community), where initial biomass was the largest. Trampling fragmented the vegetation which was scattered across the transect or washed away. A large fraction of the fragmented vegetation (*c*. 50% of biomass) remained in the transect in a damaged condition which can potentially act as a propagule bank. A key issue here involves whether the erosion exceeds the recovery capacity of the remaining biomass or the growth rate of new propagules (Smith 1993, Johansson & Thor 2008).

Impact mitigation

Spatial strategies for minimizing impacts of trampling by visitors in natural parks are discussed in Leung & Marion (1999) and, for the case of Antarctica, in Tejedo *et al.* (in press). Here we detail some lessons learnt from the present study for the minimization of damages to existing communities. First, due to the extreme sensitivity of cryptogamic communities, the best approach should always be to avoid disturbing them. Alternative routes should be considered. For instance, bare soils could be more resilient to low traffic. For this approach Tejedo *et al*. (2009) contains more detailed recommendations. Also, stream beds have traditionally been considered as another alternative route; however there is little knowledge about the effects of human traffic on fresh water ecosystems.

To avoid short-term irreversible damage to moss carpet communities (A), access should be forbidden to any large groups. In general, shore visits for tourist groups are managed so that only 100 people are on shore at any one time, with one guide for every 20 tourists (IAATO 2011). These numbers are sufficient to cause severe damage which can easily spread over a large area. If the only option is to cross over an area covered by moss carpet communities, a sacrificial path that is precisely defined will be a more preferable solution than letting the group spread over a large area. Nonetheless this will not only inevitably lead to the destruction of the moss community along the path but will also turn the path into a muddy area. This is due to the relatively high contents of water and biomass. These muddy areas are likely to expand as people try to avoid the existing muddy area by making detours, thereby increasing the width of the path and creating even more muddy areas, an idea expressed already in Gremmen *et al*. (2003) and recently reported in Barrientos Island (Equador & Spain 2012). Thus, from the perspective of the protection of these cryptogam communities group leaders should ensure that members of their group remain on the path. For small groups of no more than 1–5 people passing through this area once or twice, such as scientific expeditions, our recommendation would be that they spread out, since the trampling intensity is insufficient to produce direct impact as long as the trampling pressure is not reproduced. The impact can be easily spotted by the characteristic indentations on the moss carpet (Fig. 3).

In contrast, damages on moss hummock communities (B) can become difficult to detect since the visual impact is less identifiable than in A (Fig. 3). Large groups might not observe any visible damage after their pass and may feel free to walk there, but the damage is gradual and cumulative, and visitors should be restricted to the sacrificial path in order to avoid extended denudation processes. It should be remembered that, as found in the samples studied, this community contains a high diversity of bryophytes with rare moss species.

The lichen fellfield community (C) shows a high degree of sensitivity. Each pedestrian transit creates direct impact and spreading is not an option, not even for small groups. The impact on this community is not easily visualized due to the low biomass and cryptic colours, with dominant black and grey shades (Fig. 3). Elevated zones with exposed lichen formation should be avoided by groups to the maximum extent.

Conclusions

The three cryptogam communities studied are all highly sensitive to trampling. Vegetation cover, soil characteristics, water content and biomass were identified as relevant aspects for the understanding of the denudation process. High sensitivity was related to extreme hydration and relatively large biomass in one community and to extreme dryness and a weak attachment of plants to the substratum in another community. The three communities behaved differently in the trampling experiments but they all exhibited low resistance of the vegetation to trampling. Different strategies are suggested to minimize the impacts of trampling; nonetheless the basic recommendation provided by SCAR (2009) to directly avoid sensitive habitats would be the first measure to apply to all these communities. The capacity for a sustainable recovery from trampling disturbances within the context of global change relies on appropriate management systems addressing the relative vulnerabilities of terrestrial ecosystems in Maritime Antarctica (Reid 2007, Tin *et al*. 2009, Convey 2010). Thus, a key issue for the future would then involve the study and monitoring of the resilience of the plant communities.

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Supplemental material

A supplemental table will be found at http://dx.doi.org/10.1017/S095410201200082X

References

ASOC (Antarctic and Southern Ocean Coalition). 2004. *Environmental reports of Fildes Peninsula, 1988–1997: benchmarks for environmental management*. Antarctic and Southern Ocean Coalition Report, December 2004, 15 pp.

ATCM (Antarctic Treaty Consultative Meeting). 2011. Management Plan for Antarctic Specially Protected Area No. 126 Byers Peninsula, Livingston Island, South Shetland Islands. *Measure 4*, *XXXIV Antarctic Treaty Consultative Meeting, Buenos Aires, June 2011*, 23 pp.

Ayres, E., Nkem, J.N., Wall, D.H., Adams, B.J., Barrett, J.E., Broos, E.J., Parsons, A.N., Powers, L.E., Simmons, B.L. & Virginia, R.A. 2008. Effects of human trampling on populations of soil fauna in the McMurdo Dry Valleys, Antarctica. *Conservation Biology*, **22**, 1544–1551.

Bastmeijer, C.J. & Roura, R. 2004. Regulating Antarctic tourism and the precautionary principle. *American Journal of International Law*, **98**, 763–781.

Bednarek-Ochyra, H., Váňa, J., Ochyra, R. & Smith, R.I.L. 2000. *The Liverwort flora of Antarctica*. Cracow: Polish Academy of Sciences, 236 pp.

Bertram, E. 2007. Antartic ship-borne tourism: an expanding industry. *In* Snyder, J.M. & Stonehouse, B., *ed. Prospects for polar tourism*. Trowbridge: CABI, 149–169.

Beyer, L. & Bötler, M. 2002. *Geoecology of Antarctic ice free coastal landscapes*. Berlin: Springer, 463 pp.

Bremner, J.M. & Mulvaney, J.L. 1982. 1982. Nitrogen - total. *In* Page, A.L., Miller R.H. & Keeney, D.R., *eds. Methods of soil analysis*, part 2. Madison, WI: American Society of Agronomy, 595–624.

Cole, D.N. 1995a. Experimental trampling of vegetation. I. Relationship between trampling intensity and vegetation response. *Journal of Applied Ecology*, **32**, 203–214.

Cole, D.N. 1995b. Experimental trampling of vegetation. II. Predictors of resistance and resilience. *Journal of Applied Ecology*, **32**, 215–224.

Cole, D.N. & Bayfield, N.G. 1993. Recreational trampling of vegetation: standard experimental procedures. *Biological Conservation*, **63**, 209–215.

Convey, P. 2010. Terrestrial biodiversity in Antarctica: recent advances and future challenges. *Polar Science*, **4**, 135–147.

De Leeuw, C. 1994. *Tourism in Antarctica and its impact on vegetation*. PhD thesis, Groningen: Arctic Centre, University of Groningen, 38 pp. [Unpublished].

Ecuador & Spain. 2012. Revision of the visitor guidelines for visited sites: Barrientos Island (Aitcho Is.). Working Paper 59, *XXXV Antarctic Treaty Consultative Meeting*, Hobart, 10–20 June 2012.

Farrell, T.A. & Marion, L.J. 2001. Identifying and assessing ecotourism visitor impacts at selected protected areas in Costa Rica and Belize. *Environmental Conservation*, **28**, 215–225.

Farrell, T.A. & Marion, L.J. 2002. Trail impacts and trail impact management related to ecotourism visitation at Torres del Paine National Park, Chile. *Journal of the Canadian Association for Leisure Studies*, **26**, 31–59.

Frenot, Y., Chown, S.L., Whinam, J., Selkirk, P., Convey, P., Skotnicki, M. & Bergstrom, D. 2005. Biological invasions in the Antarctic: extent, impacts and implications. *Biological Reviews*, **80**, 45–72.

Fretwell, P.T., Convey, P., Fleming, H.A., Peat, H.J. & Hughes, K.A. 2011. Detecting and mapping vegetation distribution on the Antarctic Peninsula from remote sensing data. *Polar Biology*, **34**, 273–281.

Gremmen, N.J.M., Smith, V.R. & van Torengen, O.F.R. 2003. Impact of trampling on the vegetation of subantarctic Marion Island. *Arctic, Antarctic, and Alpine Research*, **35**, 442–446.

Hughes, K.A. & Convey, P. 2010. The protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. *Global Environmental Change*, **20**, 96–112.

Hughes, K.A., Fretwell, P., Rae, J., Holmes, K. & Fleming, A. 2011. Untouched Antarctica: mapping a finite and diminishing environmental resource. *Antarctic Science*, **23**, 537–548.

IAATO (International Association of Antarctic Tour-Operators). 2011. *Guidelines for visitors to the Antarctic*. http://iaato.org/es/visitor-guidelines accessed 30 June 2012.

Johansson, P. & Thor, G. 2008. Lichen species density and abundance over ten years in permanent plots in inland Drowning Maud Land, Antarctica. *Antarctic Science*, **20**, 115–121.

Lara, F. & Pertierra, L.R. In press. *Brachythecium subpilosum* (Hook. f. & Wilson) 645 A. Jaeger. *In* Ellis, L., *ed. New national and regional Bryophyte records, No. 32. Journal of Bryology*.

Leung, Y. & Marion, J.L. 1999. Spatial strategies for managing visitor impacts in National Parks. *Journal of Park and Recreation Administration*, **17**, 20–38.

Lindsay, D.C. 1971. Vegetation of the South Shetland Islands. *British Antarctic Survey Bulletin*, No. 25, 59–83.

López-Martínez, J., Martínez de Pisón, E., Serrano, E. & Arche, A. 1996. *Geomorphological map of Byers Peninsula, Livingston Island*. Cambridge: British Antarctic Survey, 72 pp.

Lynch, H.J., Crosbie, K., Fagan, W.F. & Naveen, R. 2010. Spatial patterns of tour ship traffic in the Antarctic Peninsula region. *Antarctic Science*, **22**, 123–130.

Marion, J.L. & Cole, D.N. 1996. Spatial and temporal variation in soil and vegetation impacts on campsites. *Ecological Applications*, **6**, 520–530.

Marion, J.L. & Leung, Y. 2001. Trail resource impacts and an examination of alternative assessment techniques. *Journal of Park and Recreation Administration*, **19**, 17–37.

Navas, A., López-Martínez, J., Casas, J., Machín, J., Durán, J.J., Serrano, E., Cuchi, F. & Mink, S. 2008. Soil characteristics on varying lithological substrates in the South Shetland Islands, maritime Antarctica. *Geoderma*, **144**, 123–139.

Nelson, D.W. & Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. *In* Page, A.L., Miller R.H. & Keeney, D.R., *eds. Methods of soil analysis*, part 2. Madison, WI: American Society of Agronomy, 539–579.

Newsham, K.K. 2010. The biology and ecology of the liverwort *Cephaloziella varians* in Antarctica. *Antarctic Science*, **22**, 131–143.

Ochyra, R., Smith, R.I.L. & Bednarek-Ochyra, H. 2008. *The Illustrated Moss Flora of Antarctica*. Cambridge: Cambridge University Press, 685 pp.

Olech, M. 1996. Human impact on terrestrial ecosystems in West Antarctica. *NIPR Symposium on Polar Biology Proceedings*, No. 9, 299–306.

Olsen, R.S., Cole, V.C., Watanabe, F.S. & Dean, L.A. 1954. *Estimation of available phosphorus in soils by extraction with sodium bicarbonate*. Washington, DC: USDA Circular 939.

Øvstedal, D.O. & Smith, R.I.L. 2001. *Lichens of Antarctica and South Georgia: a guide to their identification and ecology*. Cambridge: Cambridge University Press, 424 pp.

Putzke, J. & Pereira, A.B. 2001. *The Antarctic mosses, with special reference to the South Shetland Islands*. Ulbra: Editora Da Ulbra, 196 pp.

Quesada, A., Camacho, A., Rochera, C. & Velázquez, D. 2009. Byers Peninsula: a reference site for coastal, terrestrial and limnetic ecosystem studies in maritime Antarctica. *Polar Science*, **3**, 181–187.

Reid, K. 2007. Monitoring and management in the Antarctic making the link between science and policy. *Antarctic Science*, **19**, 267–270.

Roser, D.J., Seppelt, R.D. & Nordstrom, O. 1994. Soluble carbohydrate and organic acid content of soils and associate microbiota from the Windmill Islands, Budd Coast, Antarctica. *Antarctic Science*, **6**, 53–59.

Sancho, L.G., Schulz, F., Schoeter, B. & Kappen, L. 1999. Bryophyte and lichen flora of South Bay, Livingston Island: South Shetland Islands, Antarctica. *Nova Hedwigia*, **68**, 301–337.

SCAR (Scientific Commitee on Antarctic Research). 2009. *Environmental code of conduct for terrestrial scientific field research in Antarctica*. www.scar.org/researchgroups/lifesciences/Code_of_Conduct_Jan09.pdf accessed 21 December 2011.

Scott, J.J. & Kirkpatrick, J.B. 1994. Effects of human trampling on the sub-Antarctic vegetation of Macquarie Island. *Polar Record*, **30**, 207–220.

Smith, R.I.L. 1988. Destruction of Antarctic terrestrial ecosystems by a rapidly increasing fur seal population. *Biological Conservation*, **45**, 55–72.

Smith, R.I.L. 1993. The role of bryophyte propagule banks in a primary succession: case study of an Antarctic fellfield soil. *In* Miles, J. & Walton, D.W.H., *eds. Primary succession on land*. Oxford: Blackwell Scientific Publications, 55–78.

Smith, R.I.L. 1994. Vascular plants as bioindicators of regional warming in Antarctica. *Oecologia*, **99**, 322–328.

Smith, R.I.L. & Richardson, M. 2011. Fuegian plants in Antarctica: natural or anthropogenically assisted immigrants? *Biological Invasions*, **13**, 1–5.

Tejedo, P., Justel, A., Rico, E., Benayas, J. & Quesada, A. 2005. Measuring impacts on soils by human activity in an Antarctic Special Protected Area. *Terra Antarctica Reports*, **12**, 57–62.

Tejedo, P., Justel, A., Benayas, J., Rico, E., Convey, P. & Quesada, A. 2009. Soil trampling in an Antarctic Specially Protected Area: tools to assess levels of human impact. *Antarctic Science*, **21**, 229–236.

Tejedo, P., Pertierra, L., Benayas, J., Convey, P., Justel, A. & Quesada, A. In press. Trampling on maritime Antarctica: can soil ecosystems be effectively protected through existing codes of conduct? *Polar Research*.

Thomas, D.N., Fogg, G.E., Convey, P., Fritsen, C.H., Gili, J.M., Gradinger, R., Laybourn-Parry, J., Reid, K. & Walton, D.W.H. 2008. *The biology of Polar Regions*, 2nd ed. Oxford: Oxford University Press, 394 pp. Q3

Thomas, G.W. 1982. Exchangeable cations. *In* Page, A.L., Miller, R.H. & Keeney, D.R., *eds. Methods of soil analysis*, part 2. Madison, WI: American Society of Agronomy, 154–165.

Thor, G. 1997. Establishment of permanent plots with lichens and mosses for monitoring local human impact on environment in Heimefrontfjella and Vestfjella, Dronning Maud Land, Antarctica. *Antarctic Record*, **41**, 652–672.

Tin, T., Fleming, Z.L., Hughes, K.A., Ainley, D.G., Convey, P., Moreno, C.A., Pfeiffer, S., Scott, J. & Snape, I. 2009. Impacts of local human activities on the Antarctic environment. *Antarctic Science*, **21**, 3–33.

Toro, M., Camacho, A., Rochera, C., Rico, E., Bañón, M., Fernández-Valiente, E., Marco, E., Justel, A., Vincent, W.F., Avendaño, M.C., Ariosa, Y. & Quesada, A. 2007. Limnological characteristics of the freshwater ecosystems of Byers Peninsula, Livingston Island, in maritime Antarctica. *Polar Biology*, **30**, 635–649.

Turner, J., Colwell, S.R., Marshall, G.J., Lachlan-Cope, T.A., Carleton, A.M., Jones, P.D., Lagun, V., Reid, P.A. & Iagovkina, S. 2005. Antarctic climate change during the last 50 years. *International Journal of Climatology*, **25**, 279–294.

Vaughan, D.G., Marshall, G.L., Connolley, W.L., Parkinson, C., Mulvaney, R., Hodgson, D.A., King, J.C., Pudsey, C.J. & Turner, J. 2003. Recent rapid regional climate warming on the Antarctic Peninsula. *Climatic Change*, **60**, 243–274.

West, M.H. & Maxted, A.P. 2000. An assessment of tundra degradation resulting from the presence of a field camp in Kongsfjorden, Svalbard. *Polar Record*, **36**, 203–210.

4.2 Poa pratensis, ¿una planta no nativa exitosa en la Antártida?

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Resumen Una colonia aislada de la hierba no-nativa, *Poa pratensis*, que fue introducida de manera inadvertida en la Caleta Cierva, Península Antártica, en el verano austral de 1954-55, sigue presente hoy en día tras una inspección en Febrero de 2012, convirtiéndola en la colonia persistente más antigua de una planta vascular no nativa de la Antártida. Desde un reconocimiento anterior de la planta en 1991 la hierba ha triplicado su extensión, con un crecimiento anual del área de aproximadamente 0.019 m^2, con una velocidad de crecimiento radial máxima de 1.43 cm por año. Pese al florecimiento anual de las plantas, hemos observado que estas no llegan a producir semillas y las estructuras reproductoras tienen un desarrollo incompleto. Las condiciones ambientales, en particular las bajas temperaturas del verano austral pueden estar inhibiendo la reproducción sexual. Por su parte la falta de una efectiva dispersión vegetativa puede deberse a (1) el pequeño tamaño de la colonia, (2) las condiciones físicas y micro climáticas del lugar de introducción que restringen la dispersión por el viento o las aves, y (3) los bajos niveles de actividad humana en el enclave limitando las oportunidades de dispersión mediada por el hombre. Aunque la Poa pratensis ha estado presente en Caleta Cierva durante casi 60 años no se ha convertido en invasora. Los escenarios para los futuros desarrollos potenciales de la especie en la Antártida son discutidos en el contexto del cambio climático. Finalmente se describe el riesgo medioambiental que presenta la Poa pratensis y se defiende la necesidad de erradicar esta especie no-nativa con la mayor urgencia.

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Palabras clave: Hierba azul de Kentucky, Floración, Temperaturas de verano, agentes dispersores

Poa pratensis, a successful non-native plant in the Antarctic?

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Abstract A single colony of the non-native grass, *Poa pratensis*, which was introduced inadvertently to Cierva Point, Antarctic Peninsula, during the 1954-55 season, was still present during a survey in February 2012, making it longest surviving non-native vascular plant colony in Antarctica. Since an earlier survey of the grass in 1991 the grass mat has tripled in size, with an annual increase in area of approximately 0.019 m^2, with an estimated maximum radial growth rate of 1.43 cm y^{-1}. Despite annual flowering of the plants, no seed production and only incomplete development of the sexual structures were observed. Current environmental conditions, including low temperatures, may inhibit sexual reproduction. Lack of effective vegetative dispersal, to date, may be due to the (i) small extent of the colony, (ii) physical and microclimatic characteristics of the introduction site, which may restrict either wind or bird dispersal, and (iii) low level of human activity at the site that may have limited opportunities for human-mediated dispersal. Although *P. pratensis* has existed at Cierva Point for almost 60 years, it has not yet become invasive. Scenarios for the potential future development of the species in Antarctica are discussed in the context of regional climate change. Finally, we describe the environmental risk presented by *P. pratensis* and argue that this non-native species should be eradicated as soon as possible.

Keywords: Kentucky bluegrass · Flowering · Summer temperatures · Dispersal agents

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Introduction

Climate change in peninsular Antarctica may present new threats to terrestrial ecosystems particularly by increasing the likelihood of successful establishment of non-native species (Convey et al. 2007; Hughes and Convey, 2010). Once established, non-native species may become invasive and out-compete native organisms (Molina-Montenegro et al. 2012) and spread beyond their original introduction site (Frenot et al. 2005). Introductions of non-native species, from a wide variety of biological groups, have been reported extensively within the sub-Antarctic islands and increasingly in Maritime Antarctica (Frenot et al. 2005; Hughes and Worland 2010) and their spatial distribution is correlated strongly with the location of human activities throughout the continent (Tin et al. 2009; Lee and Chown 2009; Hughes et al. 2010). As climate change continues within the Antarctic Peninsula region and extends to the rest of Antarctica over the coming decades, biological invasions may present an increasing threat to terrestrial biodiversity and a major challenge for Antarctic conservation (Hughes and Convey 2010; Chown et al. 2012).

The intentional introduction of non-native species to the Antarctic Treaty area is now largely prohibited by the Protocol on Environmental Protection to the Antarctic Treaty (signed in 1991, entered into force 1998). However, during the 1940s, 50s, 60s and 70s, scientist from several nations undertook transplantation experiments, predominantly in the Antarctic Peninsula region, South Shetland Islands and South Orkney Islands, to assess the ability of non-native plants to survive under Antarctic conditions (e.g. *Acaena magellanica* Vahl., *Festuca contracta* Kirk, and *Poa flabellata* (Lam.) Raspail). Few non-native plants that were introduced intentionally survived longer than 2-3 years. Nevertheless, these transplantation experiments often necessitated the importation of non-sterile soils (e.g. from the sub-Antarctic islands or Patagonian) that contained propagules, such as seeds, insect eggs, plant fragments, or even adult plants, which provided the opportunity for unintended non-native species introductions (Smith 1996; Hughes and Worland 2010).

Non-native plant that are known to have established in Antarctica include *Poa pratensis* L. (commonly known as smooth meadow grass, Kentucky bluegrass or common meadow grass) and *P. annua* L. (annual meadow grass or annual bluegrass), but a recent report suggests that the rush *Juncus bufonius* L. var. *bufonius* may be found near Arctowski station within Antarctic Specially Protected Area 128 Western Shore of Admiralty Bay, King George Island (Cuba-Diaz et al., 2012). *Poa pratensis* was possibly the first recorded vascular plant introduced inadvertently to Antarctica that survived over-wintering, having tolerated conditions on Deception Island (South Shetland Islands) between 1944 and 1948 (Longton 1966). *Poa annua* was the second plant reported to have established in Antarctica, having been introduced to several locations during the latter half of the 20th century including Deception Island, Signy Island (South Orkney Islands) and Galindez Island (Argentine Islands, Antarctic Peninsula). Eventually these populations died out, with the Deception Island population being destroyed during a volcanic eruption in 1967 (Smith, 1996).

Currently *Poa annua* presents the greatest threat to Antarctic terrestrial ecosystems and is the most widespread non-native vascular plant in Antarctica. Following an introduction in 1985-86 to Arctowski Station, King George Island, *P. annua* has now spread c.1.5 km away from the station (Olech 1996; Chwedorzewska 2007; Olech and Chwedorzewska 2011) and the species has also been found near research stations at three other locations in the Antarctic Peninsula (General Bernardo O'Higgins, Gabriel González Videla and Almirante Brown Stations) (Molina-Montenegro et al. 2012). In contrast, the known distribution of *P. pratensis* is much more restricted. *Poa pratensis* was introduced inadvertently to Cierva Point, Danco Coast, Antarctic Peninsula, during transplantation experiments in 1954-55 (Corte 1961). *Nothofagus antarctica* (G. Forst.) Oerst. (Antarctic beech) and *N. pumilio* (Poepp. & Endl.) Krasser (lenga beech) trees were transplanted from Tierra de Fuego to Cierva Point to assess their capacity for survival in Antarctica. The trees did not survive wintering. However, the accompanying grass became established within the original experimental plot and survived to the present, representing the longest survival of a non-native plant in the Antarctic. After Corte's report of 1961, the next available information on the colonization status of *P. pratensis* was from the summer of 1990-91, when N. Scutari informed Smith (1996) that the grass was limited to a single circular colony of approximately 40 cm in diameter. In 1995, O. Benitez observed immature inflorescences and reported that the colony was still limited to within the original experimental plot (Smith 1996). In February 2012 we visited the site and evaluated the distribution and characteristics of the introduced grass population. Here we present the results of this survey, describe the reproductive strategies available to the plant and discuss the potential future of *P. pratensis* at Cierva Point.

Methods

Cierva Point (Punta Cierva), Danco Coast, Northwest Antarctic Peninsula (64º10´S, 60º57´W) is an ice-free area of ca. 3 km^2 where the Argentinean "Primavera" research station is located. The site contains several small rock outcrops with predominantly north-facing slopes, which produces climatic conditions favourable for plant growth (Mataloni et al. 1998). Vegetation is extensive between outcrops with large moss carpets growing together with moss and lichens communities and swards of the native grass *Deschampsia antarctica* Desvaux. Several marine bird species are also present, including a gentoo penguin (*Pygoscelis papua*) colony. A single report exists of a non-native insect of the order Mecoptera (a snow scorpion fly; possibly a *Boreus* sp.) at the site, but its current colonization status and distribution is unknown (Convey & Quintana 1996).

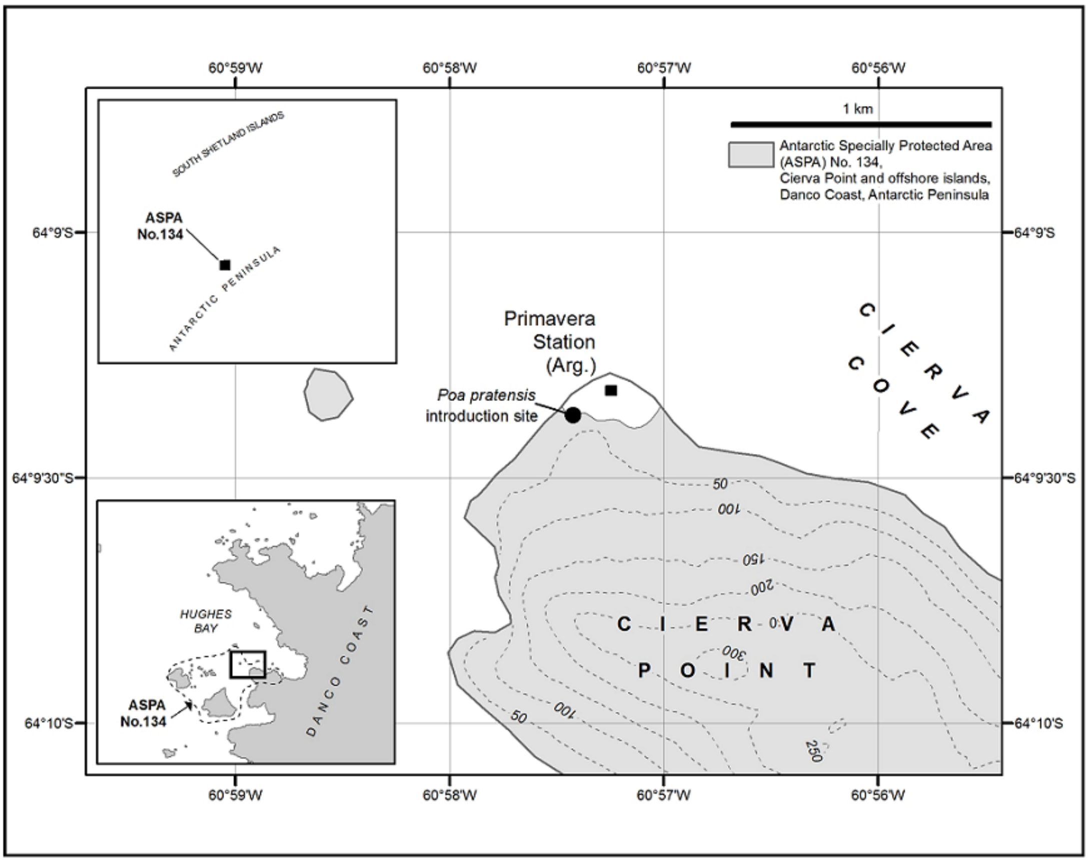

Fig. 1. Location map showing the position of the *Poa pratensis* introduction site on Cierva Point.

In February 2012 we investigated the distribution of *Poa pratensis* within an area of approximately 1 km^2 around the original transplantation site. No *P. pratensis* plants, other than the colony at the original introduction site, were found. The colony was geo-positioned and photographed. The extent of the colony's perimeter was measured. The mean growth rate between 1991 and 2012 was calculated based upon the report of N. Scutari, contained within Smith (1996), which stated that the plant was restricted to a circle of 40 cm in diameter within the original plot. Samples of flowered grass plants were collected for later examination in the laboratory. Samples of the indigenous flora (mosses and phanerogams) were also collected for identification in the laboratory. Specimens were kept in herbaria at the Universidad Autónoma de Madrid and the British Antarctic Survey (international codes MAUAM and AAS, respectively).

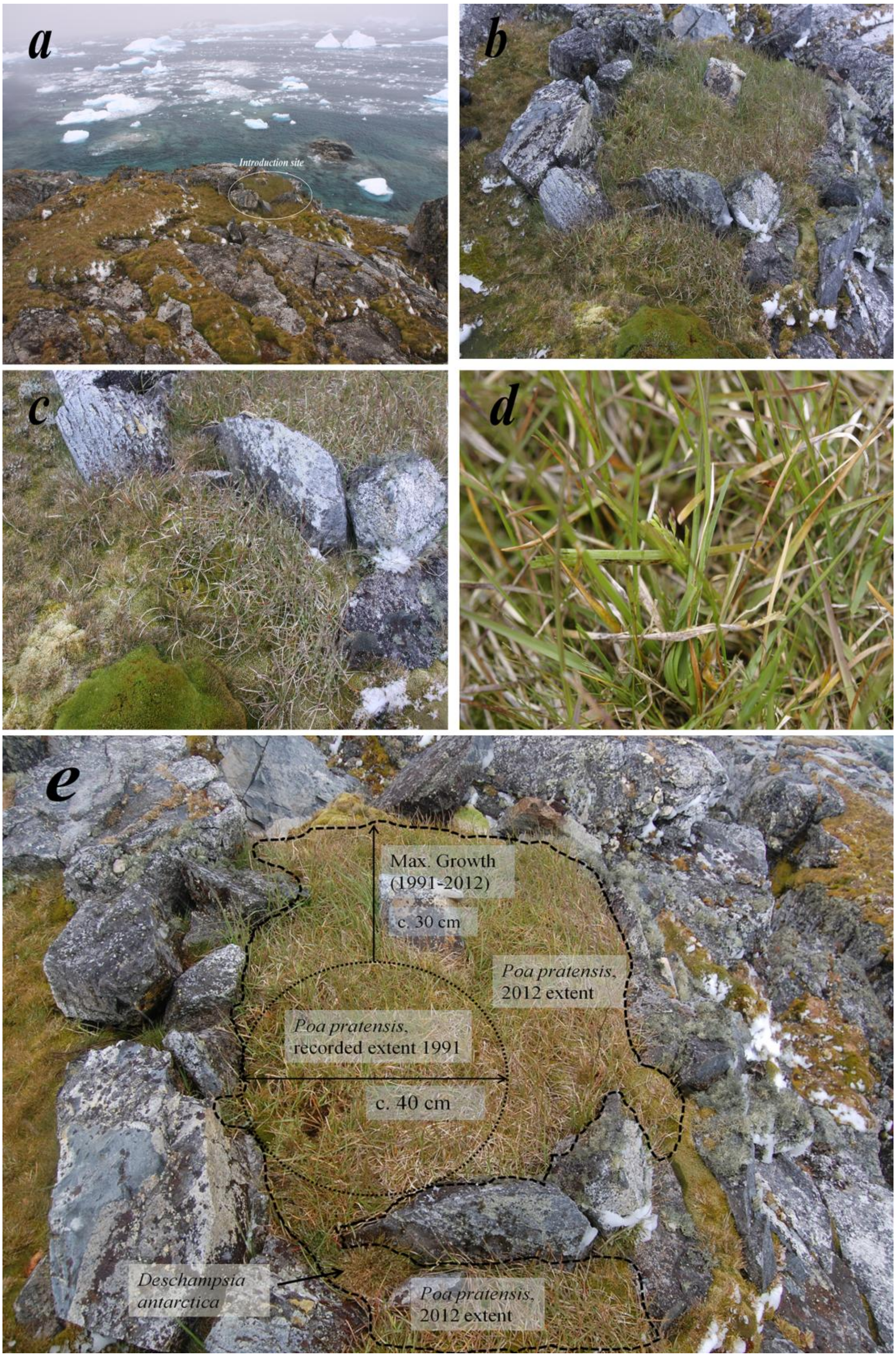

Fig. 2. *Poa pratensis* at Cierva Point. (a) The immediate vicinity of the introduced plant colony. (b) The original plot colonized by *P. pratensis*. (c) Adjacent growth of *P. pratensis* and native plants beyond the limits of the original plot. (d) *P. pratensis* flowering. (e) Total extent of the colony in February 2012, with the extent of the colony in 1991 shown (plant c. 40 cm in diameter).

Meteorological information was obtained from the SCAR READER project, hosted by the British Antarctic Survey and available at: http://www.antarctica.ac.uk/met/READER/data.html. Available temperature data for the local area over the last two decades were obtained from the Racer Rocks meteorological station (64°04'S, 61°36'W) located ca. 30 km northwest of Cierva Point. In common with the *P. pratensis* introduction site on Cierva Point, the Racer Rocks meteorological station is positioned on the coast c. 17 m a.s.l. Temperatures were recorded during the period 1989-2003. A complete record of average monthly temperatures for all austral summer months (November to March) was available for only three years (1990-91, 91-92, 99-00). Mean monthly temperature data existed for nine other years were one or more monthly record contained data with less than 90% of the daily data available (i.e. summer seasons 1989-90, 92-93 to 98-99 and 2000-01). Mean monthly temperatures from seasons 2001-02 and 2002-03 were not calculated due to the poor quality of the dataset. Due to their close proximity (30 km), temperature data from Racer Rocks may reflect temperature conditions on Cierva Point. Temperatures maxima and minima for each month of the summer season (November-March), recorded during the period 1989 and 2001, were used to produce a 'best fit' curve for upper and lower temperatures, respectively.

Results

The field survey found a single stand of *Poa pratensis* at 64º09'20.9'' S, 060º57'20.5'' W (Fig 1). The grass mat was growing in shallow soil over bedrock, situated ca. 20 m a.s.l. and ca. 25 m from the coast. The dense grass mat covered an area of 0.53 m^2, and formed a rough rectangle with sides of ca. 0.7 and 1.0 m (0.64 m^2) with boulders within it (0.11 m^2). The mat size described in Smith (1996) corresponded to an area of 0.12 $m^{2.}$. After 21 years the grass mat has extended beyond the boundary of the original plot, originally delimited with small boulders. Compared with the previous record, *P. pratensis* has extended its area of coverage by 0.44 m^2 since 1991, with an estimated mean expansion of 0.019 $m^2\ y^{-1}$. In places where grass growth was not restricted by boulders, linear growth has reached up to ca. 30 cm in 21 years, giving a maximum mean linear growth rate of 1.43 cm y^{-1}.

Plants in the colony were healthy (Figs. 2 and 3) and numerous individuals were flowering (Fig 2d). Intermixed with the colony were tufts of two terricolous mosses, *Sanionia uncinata* (Müll & Hall) Ochyra & Hedenäs, and *Syntrichia magellanica* (Mont.) R.H. Zander. Both mosses tolerate a wide range of conditions and are common throughout the Antarctic Peninsula (Ochyra et al. 2008). Within the plot, small well-developed tussocks of *Deschampsia antarctica* were found (Fig 2e) alongside small portions of detached lichens (*Usnea spp.*)

Examination of *Poa pratensis* spikes that developed that growing season and the remnants of spikes from the previous growing season revealed incomplete development of the reproductive structures inside the spikes (Fig. 3). The spikes contained from one to three flowers. Inside them, the reproductive structures (both anthers and pistil) were under-developed or aborted, and had not formed mature organs (Fig. 3d-e). In consequence, no fecundation was achieved and seeds were absent.

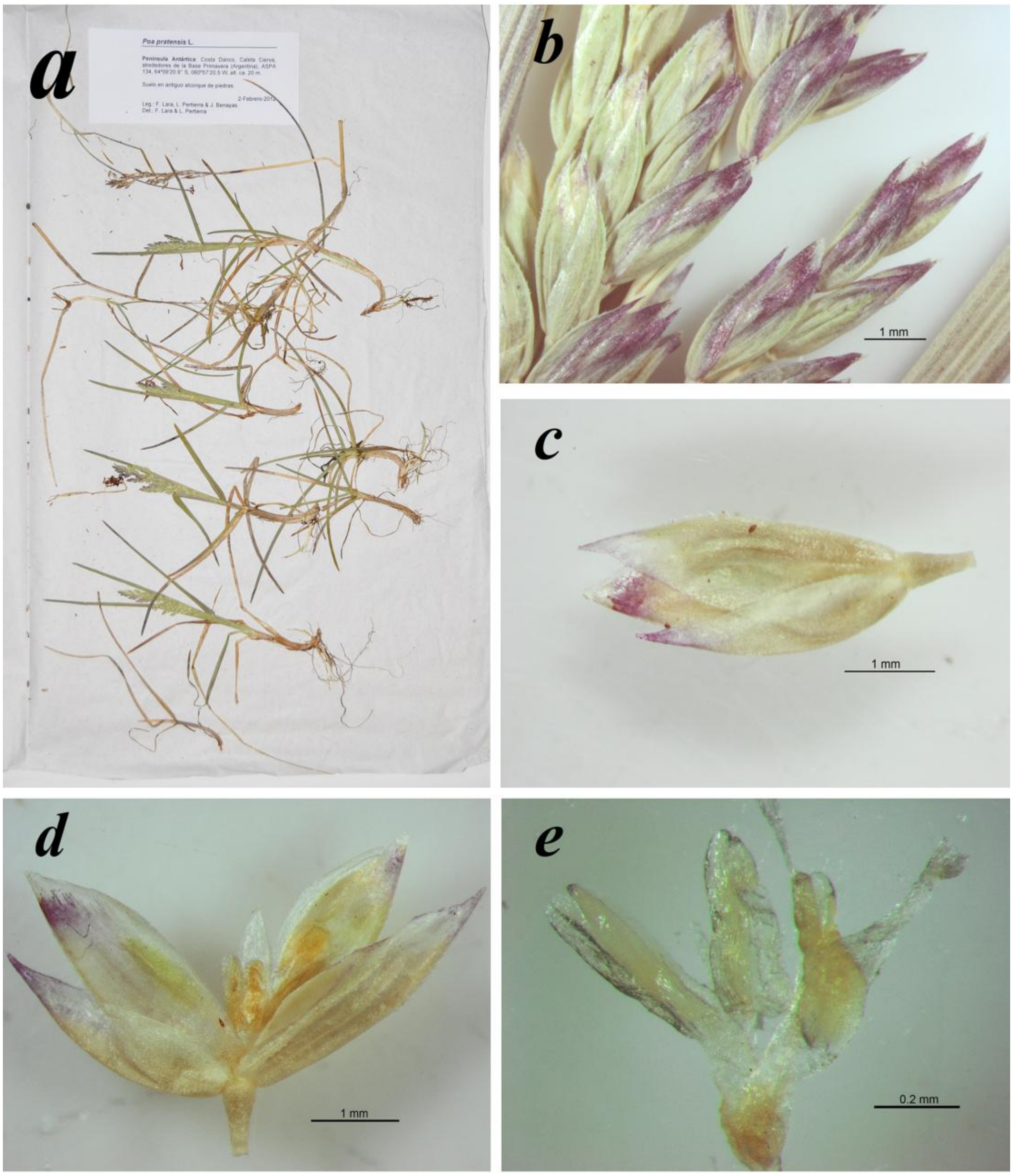

Fig. 3. Examination of *Poa pratensis* materials from Cierva Point. (a) Specimens from a sheet kept at MAUAM Herbarium (label measured 12.1 x 5.2 cm), (b) detail of an inflorescence, (c) spikelet, (d) open spikelet, showing in the centre the anthers of two stamens corresponding to the basal floret, (e) dissected floret, showing its three stamens; the anthers do not contain developed pollen grains; the pistil is aborted.

Available temperature data from Racer Rocks for the period 1990-2001 showed a maximum average monthly temperature in February 1990 of 2.2 ^{o}C (Fig 4).

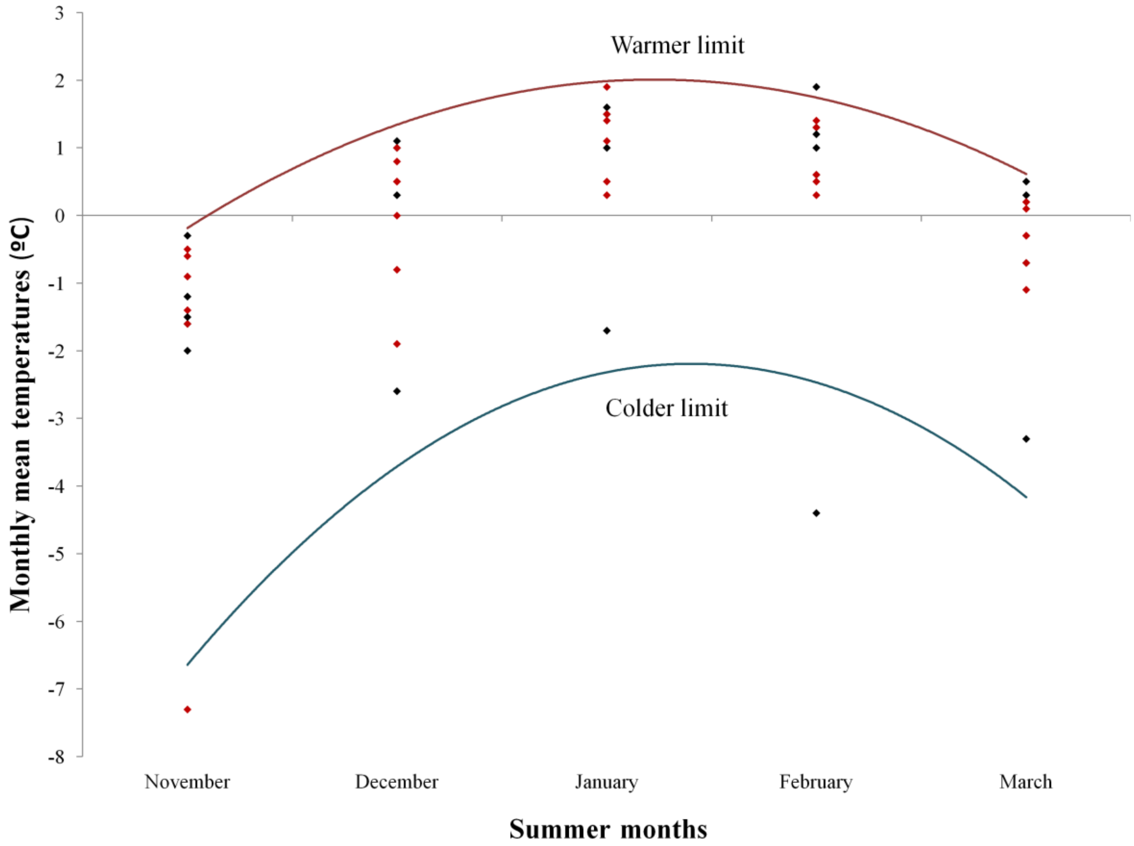

Fig. 4. Mean monthly temperature records from Racer Rocks Station (64° 04' 00.0" S, 61° 36' 00.0" W), located 30 km northwest of Cierva Point. Summer seasons data (November-March), where values are available for all five months, are shown by black diamonds, while seasons where data is only not available for all five summer months are shown by red diamonds. For each month during the summer season, maximum and minimum mean monthly temperatures, recorded between 1989 and 2001, were used to produce a 'best fit' curve for upper and lower temperatures, respectively.

Discussion

Our survey has shown that *Poa pratensis* has survived 57 Antarctic winters at Cierva Point and in the last two decades has started to expand its distribution. Beard (1966), undertaking physiological studies in the laboratory, showed *P. pratensis* to be tolerant of low temperatures, and more so than other turf grasses including *P. annua*. In experiments, Guldeifson (1986) found that at temperatures as low as 15^{o}C, 50% of *P. pratensis* plants were able to survive, but he also found that plants showed progressive tolerance both to cold hardiness in the laboratory and wintering stress in the field. These studies may go some way to explain the Antarctic winter hardiness of the grass.

In contrast our study showed that the Cierva Point *P. pratensis* colony had not produced mature flowers by late in the growing season, and plants were unlikely to be capable of sexual reproduction. While the *Poa pratensis* colony is well-able to survive wintering conditions, the environmental conditions may not be suitable for completion of sexual reproduction, which is supported by the report of immature inflorescences in the grass at Cierva Point in 1995 (Smith, 1996). Dedicated studies have shown that *Poa pratensis* requires dual floral induction requirements to produce seeds; a first stage of low temperatures (below 5ºC) and short days that stimulate tiller emergence and primary floral induction which is followed by over-wintering and vernalization, and a second stage of elongation of tillers and floral development that requires long days and temperatures above 10ºC (Heide et al. 1987, Holman and Thill 2005). Meteorological records for the general area showed a cold summer temperature regime with temperatures peaking in January-February slightly over 0 ºC (Fig 4) which would be preventing the second stage of floral development.

In addition to sexual dispersal, Kentucky bluegrass can also undergo vigorous vegetative reproduction from rhizomes that even prevent other plants from establishing nearby (Holman and Thill 2005). At Cierva Point the vegetative growth of *Poa pratensis* has roughly tripled the extent of the colony in a little more than two decades, albeit on a small spatial scale. Malyshev et al. (2012) found a switch from reproductive to vegetative growth with increasing stress, induced, for example, by severe freezing conditions or scarcity of nutrients. In Antarctica both the general scarcity of nitrogen and severe winter conditions can cause the plants to undertake vegetative growth during the austral summer, allowing it to survive in polar conditions.

Expansion of the plant is constrained, it seemingly, by the environmental conditions, and in particular, temperature. Summer temperatures at in the area, and in the western Antarctic Peninsula in general (Turner et al. 2009), are far below the optimum for *P. pratensis* seed germination of around 10-15ºC (Tarasoff et al. 2007). Nevertheless, the western Antarctic Peninsula has been identified as the region of Antarctica with the fastest rate of warming, which may be linked with the local expansion of native vascular plants (Fowbert and Smith 1994; Smith 1994; Turner et al. 2009). It is difficult to determine the effect of climate change on the increased distribution and abundance of the non-native grass *P. annua*, although in recent years the grass has expanded its range substantially from its introduction site at Arctowski Station and colonized ground newly-exposed from beneath a retreating glacier (Olech and Chwedorzewska 2011). Discovery of *P. annua* at three other research stations on the northern Peninsula that are also subject to climate change is therefore a cause of major concern (Molina-Montenegro, 2012).

Non-native plant species in the sub-Antarctic and Antarctic may be further dispersed by both anthropogenic and natural means (Frenot et al. 2005; Chown et al. 2012; Molina-Montenegro et al. 2012). In the case of *Poa pratensis* at Cierva Point any possible dispersal events that have occurred have had no observed effects and any potentially dispersed propagules have not become established in the local area. The location of *P. pratensis* at Cierva Point on an isolated rocky peninsula with no vehicle traffic and limited foot access, suggests that the risk of further propagule dispersal by humans may be low. Dispersal of propagules by birds is possible, but the risk may be low due to the limited extent of the colonized area (Vera 2011, Parnikova et al. 2012). Wind-dispersal of plant fragments is still likely, even allowing for the sheltered nature of the site, but micro-climatic conditions away from the original introduction site may not be favourable for *P. pratensis* growth. Lack of colony spreading may be due, therefore, to the local microclimate, the small size of the established population and the isolation of the site.

Three natural future scenarios exist for the Cierva Point *P. pratensis* population: the colony may eventually (1) die out, perhaps due to an extreme weather event, (2) persist around the area of the original introduction plot or (3) expand beyond the original location, assisted potentially by either natural or anthropogenic means. Given the long persistence of the plant at the site, on-going climate warming in the region and likely further human activity in the area, the last scenario may be the most probable, with unknown consequences for local indigenous biological communities (Turner et al. 2009, Chown et al. 2012). ASPA 134 Cierva Point and offshore islands, Danco Coast, Antarctic Peninsula was designated primarily to protect the well-developed maritime vegetation and breeding colonies of at least five bird species (ATCM 2006). Spread of the non-native *P. pratensis* may put at risk the values for which the ASPA was designated.

Management of non-native plants within Antarctica has a patchy record. A single vascular plant (*Pucinella* sp. formerly identified as *Poa trivialis* L.) thought to have originated from the Arctic was found at a field hut near Syowa station but was eradicated in 2007 without flowering (Tsujimoto, pers. comm). In January 2010 the dicotyledonous plant *Nassauvia magellanica* J.F. Gmel. found at Whalers Bay, Deception Island, was eradicated one year after its discovery (Smith and Richardson, 2010; Hughes and Convey 2012). However, the lack of early action to remove *P. annua* from the vicinity of Arctowski Station when first discovered in the mid 1980s, has allowed the plant to spread over 1.5 km from the original introduction site and into ASPA 128 Western Shore of Admiralty Bay, King George Island (Chwedorzewska 2007). Thus, if effective control or eradication of a non-native plant is to be achieved it is essential that management action is taken before plants spread. The CEP *Non-native species manual* (Edition 2011) states that a key factor when responding to a non-native species introduction will be to assess the feasibility and desirability of an eradication attempt. Eradication of *P. pratensis* seems feasible due to the current localized extent of the plant's distribution (Hughes & Convey 2012). Given that climate change may increase the likelihood of further growth and spread of *P. pratensis,* with potentially serious implication for indigenous communities, it may be highly desirable to eradicate the plant as soon as possible.

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References

ATCM - Antarctic Treaty Consultative Meeting (2006) *Management Plan forAntarctic Specially Protected Area No. 134 Cerva Cove, Danko Coast.* Measure 1 Annex D, ATCM XXIX Edimburg, 12 - 23 June.

Chwedorzewska KJ (2007) *Poa annua* L. in Antarctic: searching for the source of introduction. Polar Biol 31: 263–268

Chown SL, Huiskes AHL, Gremmen NJM, Lee JE, Terauds A, Crosbie K, Frenot Y, Hughes KA, Imura S, Kiefer K, Lebouvier M, Raymond B, Tsujimoto M, Ware C, Van De Vijver B, Bergstrom DM (2012) Continent-wide risk assessment for the establishment of non indigenous species in Antarctica. Proc Nat Acad Sci 109: 4938-4943

Chown SL, Gremmen NJM, Gaston KJ (1998) Ecological biogeography of Southern Ocean islands: species-area relationships, human impacts, and conservation. American Naturalist 152: 562–575

Convey (2006) Antarctic Climate change and its influence on terrestrial ecosystems, in Bergstrom, P. Convey and A.H.L. Huiskes (eds.) *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator*. Springer, Dordrecht.

Convey P, Frenot Y, Gremmen N, Bergstrom DM (2006) Biological invasions, in D.M. Bergstrom, P. Convey, and A.H.L. Huiskes (eds.), *Trends in Antarctic Terrestrial and Limnetic Ecosystems: Antarctica as a Global Indicator,* Springer, Dordrecht.

Corte A (1961) La primera fanerógama adventicia hallada en el continente antártico. Contribución del Instituto Antártico Argentino 62, 14 pp.

Cuba-Diaz M, Troncoso JM, Cordero C, Finot VL, Rondanelli-Reyes M (2012) *Juncus bufonius*, a new non-native vascular plant in King George Island, South Shetland Islands. Antarctic Science doi:10.1017/S0954102012000958

Frenot Y, Chown SL, Whinam J, Selkirk P, Convey P, Kotnicki M, Bergstrom D (2005) Biological invasions in the Antarctic: extent, impacts and implications. Biol Rev 80: 45-72

Fowbert JA, Smith RIL (1994) Rapid population increase in native vascular plants in the Argentine Islands, Antarctic Peninsula. Arct Alp Res 26: 290–296

Gudleifsson BE, Andrews CJ, Bjornsson H (1986) Cold hardiness and ice tolerance of pasture grasses grown and tested in controlled environments. Can J Plant Sci 66: 601-608

Heide OM, Bush MG, Evans L (1987) Inhibitory and promotive effects of gibberellic acid on floral initiation and development in *Poa pratensis* and *Bromus inermis*. Physiol Plantarum 69: 342-350

Holman, JD, Thill D (2005) Kentucky Bluegrass: growth, developmemt and seed production. Univ Idaho, Bull. 843.

Hughes KA, Lee JE, Ware C, Kiefer K, Bergstrom DM (2010) Impact of anthropogenic transportation to Antarctica on alien seed viability. Polar Biol 33:1125–1130

Hughes KA, Convey P (2010) The protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. Glob Environ Change 20: 96-112

Hughes KA, Convey P (2012) Determining the native/non-native status of newly discovered terrestrial and freshwater species in Antarctica - current knowledge, methodology and management action. J. Environ Man 93: 52-66

Hughes KA, Worland MR (2010) Spatial distribution, habitat preference and colonization status of two alien terrestrial invertebrate species in Antarctica. Antarct Sci 22: 221-231

Lee JE, Chown, SL (2009) Breaching the dispersal barrier to invasion: quantification nd management. Ecol Applic 19: 1944–1959

Longton RE (1966) Alien vascular plants on Deception Island, South Shetland Islands. Brit. Antarctic Surv Bull 9: 55-60.

Malyshev AV, Henry HAL (2012) Frost damage and winter nitrogen uptake by the grass *Poa pratensis* L.: consequences for vegetative versus reproductive growth. Plant Ecol 213: 1739-1747

Mataloni G, Tesolín G, Tell G (1998) Characterization of a small eutrophic Antarctic lake (Otero Lake, Cierva Point) on the basis of algal assemblages and water chemistry. Polar Biol 19: 107-114

Molina-Montenegro MA, Carrasco-Urra F, Rodrigo C, Convey P, Valladares F, Gianoli E (2012) Occurrence of the non-native annual bluegrass on the Antarctic mainland and its negative effects on native plants. Conserv Biol 26: 717-723.

Ochyra R, Smith RIL, Bednarek-Ochyra H (2008) The illustrated moss flora of Antarctica. Cambridge: Cambridge University Press, 685 pp.

Olech M (1996) Human impact on terrestrial ecosystems in west Antarctica. Proc NIPR Symp Polar Biol 9:299–306

Olech M, Chwedorzewska KJ (2011) The first appearance and establishment of an alien vascular plant in natural habitats on the forefield of a retreating glacier in Antarctica. Antarct Sci 23: 153–154

Parnikoza I, Convey P, Dykyy I, Trakhimets V, Milinevsky G, Tyschenko O, Inozemtseva D, Kozeretska I (2009) Current status of the Antarctic herb tundra formation in the central Argentine Islands. Glob Change Biol 15: 1685–1693

Parnikoza I, Dykyy I, Ivanets V, Kozeretska I, Kunakh V, Rozhok A, Ochyra R, Convey P (2012) Use of *Deschampsia antarctica* for nest building by the kelp gull in the Argentine Islands area (maritime Antarctica) and its possible role in plant dispersal. Polar Biol 35: 1753-1758

Smith, RIL (1994) Vascular plants as indicators of regional warming in Antarctica. *Oecologia* 99: 322–328.

Smith RIL (1996) Introduced plants in Antarctica: potential impacts and conservation issues. Conserv Biol 76: 135-146.

Smith RIL, Richardson M (2011) Fuegian plants in Antarctica: natural or anthropogenically assisted immigrants? Biol Invasion 13: 1-5

Tarasoff CS, Ball DA, Mallory-Smith CA (2007) Extreme ionic and temperature effects on germination of weeping alkaligrass (*Puccinellia distans*), Nuttall's Alkaligrass (*Puccinellia nuttalliana*) and Kentucky bluegrass (*Poa pratensis*). Weed Sci 55: 305–310

Turner J, Bindschadler RA, Convey P, Di Prisco G, Fahrbach E, Gutt J, Hodgson DA, Mayewski PA, Summerhayes C, Peds (2009) Antarctic Climate Change and the Environment (Scientific Committee on Antarctic Research, Cambridge, UK). 526 pp

Tin T, Fleming ZL, Hughes KA, Ainley DG, Convey P, Moreno CA, Pfeiffer S, Scott J, Snape I (2009) Impacts of local human activities on the Antarctic environment. Antarct Sci, 21: 3-33

Vera ML (2011) Colonization and demographic structure of *Deschampsia antarctica* and *Colobanthus quitensis* along an altitudinal gradient on Livingston Island, South Shetland Islands, Antarctica. Polar Res. 30: 7146, DOI: 10.3402/polar.v30i0.7146

4.3 La corticosterona depositada en pluma: una indicación de los factores que afectan a los niveles de estrés en colonias de pingüinos Pygoscelidos

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Resumen En este trabajo se ha desarrollado el indicador corticosterona en plumas como una técnica no invasiva para el estudio del estrés en pingüinos de las tres especies del genero Pygoscelis en la Antártida Marítima. La validación de la técnica se realizó a través de toma de muestras de animales capturados en los veranos australes de 2009 y 2010. Las muestras fueron extraídas en metanol y estandarizadas por peso y por longitud de pluma. Los datos obtenidos fueron analizados estadísticamente, factores biológicos intrínsecos como la especie y el sexo fueron explorados en primer lugar. La especie es un factor diferencial, con niveles significativamente inferiores en el pingüino Adelia respecto al Gentoo, y por ello se tratan las tres especies de manera independiente. Por su parte en nuestro estudio el sexo es significativo en la especie Adelia con niveles mayores en los machos. Dentro de cada especie se encuentran diferencias significativas entre los sitios muestreados. En el caso del pingüino Gentoo aparecen diferencias entre las colonias próximas de Punta Devils y de Punta Hannah. En el caso del pingüino Barbijo aparecen diferencias entre las colonias próximas de Caleta Vapor y Punta Hannah. En el caso del pingüino Adelia aparecen diferencias entre las colonias de Islas Jalour e Isla Avian. Los factores diferenciales entre las colonias, potencialmente explicativos, son discutidos. Estos incluyen: (1) el tamaño de la colonia, (2) la presión depredadora, (3) la presencia humana y (4) la ubicación. En el marco de la frecuente interacción entre humanos y colonias de aves marinas de la Antártida los presentes resultados arrojan una indicación sobre posibles molestias derivadas de las actividades antrópicas.

Polar Biology (En preparación)

Palabras clave: Aves Marinas, Monitoreo, Salud aviar, Presencia humana

Corticosterone deposited in feathers: an indication of factors affecting stress levels of Pygoscelis penguins colonies

(En preparación)

Luis R. Pertierra · Pilar Lauzurica · Javier Benayas · Ana Justel · Andrés Barbosa

Abstract Cortiscoterone in feathers indicator was developed as a non-invasive technique for the study of stress on the three *Pygoscelis* penguin species at Maritime Antarctica. Validation of the indicator was first performed trough animal captures in 2009 and 2010. Samples were obtained through methanol extraction and standardized by feather weight and length. Data were statistically analyzed with biological factors such species and sexes being first assessed. The species was a differential factor, with significantly lower levels of corticosterone on Adelie penguin in relation to Gentoo penguin, and for this reason the three species are treated independently. In our study sex was found significant at Adelie species with higher levels on males. For each species significant differences are found among the sampled sites. In the case of Gentoo penguin significant differences are found between the close colonies of Devils Pt. and Hannah Pt. In the case of Chinstrap penguin differences are found between the close colonies of Vapour Col. and Hannah Pt. In the case of Adelie penguin differences are found between the distant colonies of Jalour Is. and Avian I. The differential factors among colonies which can be potentially explanatory, are discussed. These include: (1) site, (2) colony size, (3) predator pressure, and (4) human presence. In the scope of the frequent interaction between humans and marine birds at their colonies the present results give an indication of potential disturbances caused by anthropic activities in Antarctica.

Keywords: Monitoring · Avian Health · Rockeries · Human Presence

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Introduction

Disturbances to native fauna can lead into impacts from human presence in areas of wilderness, but no all disturbance effects produce significantly negative responses and so becomes a challenge for management (Beale 2007). In Antarctica human activities in terrestrial environments are mostly limited to the concurrence of national programs of research and tourists visits (Tin et al. 2009). Interaction with animals in land is frequent since the limited open ice-free spaces are shared both by the humans and animals. Moreover, human activity, and especially tourism, has increased in Antarctica in recent decades. Specifically, penguin colonies are one of the main attractions for Antarctic tourists as well as a strong research interest for scientists, regarding penguins as sentinels of the marine ecosystems (Barbosa et al. 2013). Human disturbance of penguins would probably cause behavioural and/or physiological changes due to increased stress, which could have negative consequences on their survival or reproduction (Walker *et al*. 2006).

Human impact may be direct by pedestrian approach (Tin *et al*. 2009), or indirect through pollution (Barbosa et al. 2013, Metcheva *et al*. 2006), or by introducing diseases in either the penguins themselves or their surroundings (Barbosa et al. 2013, Curry *et al*. 2002). Focusing on pedestrian approach and interaction some studies on penguin colonies have detected physiological changes in the animals by the sole human presence (Viblanc et al. 2012) and a later habituation but here there is no widely consensus. Many other studies on Antarctic penguins have attempted to measure this direct human impact with no clear conclusions (see the review by de Villiers 2008; but see Bonnendahl *et al.* 2005 for the only study dealing with human pathogens in penguins). Several studies have examined the effects of the approach of pedestrians on stress as measured by changes in heart beat (Nimon *et al*. 1995, Giese 1996, Holmes *et al*. 2005), while others have focused on changes in the number of penguins breeding or breeding success in visited areas compared to other places not visited (Giese 1996, Fraser & Patterson 1997, Cobley & Shears 1999, Otley 2005, Holmes *et al*. 2005, Carlini *et al*. 2007, Bricher *et al*. 2008, Trathan *et al*. 2008, Lynch *et al*. 2010).

The results of these studies are not conclusive, as some have found minimal impact of human visits on penguins with no effect on their breeding success (Fraser & Patterson 1997, Cobley & Shears 1999, Otley 2005, Holmes *et al*. 2005, Carlini *et al*. 2007), while others have found negative effects (Giese 1996, Bricher *et al*. 2008, Trathan *et al*. 2008, Lynch *et al*. 2010). Also in the case of researchers work with animal handling Vleck et al. 2000 did not find chronically increased levels on repeatedly recaptured birds (spaced by weeks) but did found increased levels on animals sampled after more than 5 minutes of capture, these studies also point out that there is a variability with animals partly in relation to environmental stressor but also due to different responses, thus requiring large enough samples to remove population-level effects.

Corticosterone levels in colonial birds reflect their adaption response to environmental stressors (Wingfield et al. 1998). Corticosterone (CORT) is the basic adrenal glucocorticod in penguins that allows fast adaptation on individuals to stressors through an increased energy supply (Holberton *et al*. 1996). These animals carry out their annual feather molting a few weeks after finishing breeding their spring during the late austral summer. In this moment that takes XX days on average, new body feathers grow to replace the old ones. During molting corticosterone circulating in blood is regarded in validation studies (Bortolotti et al. 2008, 2009), to be deposited at a regular ratio on growing feathers that comes from baseline levels of the weeks prior to feather replacement; in the case of penguins this could be giving an indication of their troubles along breeding and molting. Thus, it has been used to measure stress and fitness capacity in different situations including disturbance by human visitation (Walker *et al*. 2006, Villanueva *et al*. 2012).

In contrast, the Heterophil/lymphocyte (H/L) ratio as an expression of stress (Maxwell & Robertson 1998) has been shown as a physiological index of chronic stress in birds that may be useful in assessing response to chronic stressor (Gross & Siegel 1983). About the promoter stressors Wingfield et al. (1998) suggests corticosterone as an indicator of stress induced by famines, bad weather and agonistic interactions. In the case of long periods of fasting in penguins it was found that animals increased their cort levels after roughtly at the time of nearly depleting their fat stores Vleck et al. 2000. Weather is also regarded as a relevant conditioning (Ref XX). In the case of agonistic interactions Vleck et al. (2000) also found higher levels in adelie penguins defending their nests. Increased stress can be induced along molting but as animals stay practically immobile several environmental stressors related to their activity (such predator pressure) are supposedly not affecting them, while others related to the site interactions (such colony size) are still acting. Human disturbance is considered a main factor increasing chronic stress in animal populations.

Corticosterone response has been also measured to have an indication of human disturbance in penguins (Walker *et al*. 2006, Ellenberg *et al*. 2007, Villanueva *et al*. 2012) both for baseline and acute CORT levels in blood. In the case of human interference this still remains to be a key stressor during molting, but even if so, the acute levels of stress are to be diluted in a matter of minutes or hours in order to avoid stress-related diseases (Le Maho et al. 1992, Sapolsky 1992) while Heterophyle/Lymphocyte ratio is considered a longer lasting response to stress caused by illnesses or external injuries (Vleck et al. 2000, Barbosa et al. 2013). However these alterations, especially if frequent, may lead to a depressed baseline levels due to a exhaustion and habituation. This must not necessarily occur during molting, but along all early and middle summer prior to the feather renovation. Several studies have shown that measures of stress may be lower in animals regularly disturbed by tourists (Walker *et al*. 2006, Villanueva *et al*. 2012, but see Ellenberg *et al*. 2007) due to habituation. But if this hypothesis is right, then other environmental stressor are also acting in deposited stress levels and must be regarded. In any of these scenarios human disturbance is considered a potentially strong modulator of stress that needs to be assessed.

Our work aims to measure and compare the levels of stress in multiple penguin colonies, and to assess the effects from a set of environmental factors on these levels, in particular concerning human interference.

Methods

Site description

For each species two or three penguin rookeries with representative conditions were respectively selected to compare stress levels.

In the case of Papua penguin (*Pygoscelis papua* Forster) the protected colony of Byers was compared with the nearby visited colony of Hannah Pt to assess the effects of human presence/absence. Both are placed in Livingston Island (62ºS). Byers Peninsula is a protected area (ASPA 126 Management Plan 2012) with limited human access. It holds in Devils Pt a Papua penguin colony of ca. 3.000 breeding pairs (Fig 2A). Hannah Pt. (Fig 2B) is also a visited site with ca. 5.000 tourists per year last decade (IAATO 2012). This site holds a Papua penguin colony of 1885 breeding pairs, with a small colony inset of Chinstrap penguin (754 breeding pairs). Both sites are located at the South Shetland Islands archipelago. Finally, Ronge Island (64º S), located in the Danco Coast, Northern Antarctic Peninsula, lays ca. 100 Km. south of them. It holds a mixed colony of Papua and Chinstrap penguins, dominated by Papua´s rockeries (2462 breeding pairs) with an small inset of Chinstrap´s (354 pairs). It is a non visited site, but still deals with relatively abundant ship traffic. It faces very close in front of it the frequently visited site of Cuverville Island.

In the case of chinstrap penguin (*Pygoscelis antarctica* Foster) the small colonies located in the visited site of Hannah Pt and undisturbed site of Ronge Island (see above) were compared with the neighbor colony of Vapour Col. characterized by holding an active research, as to assess the effects of human activities: presence/handling. Vapour Col. (62ºS) is located in Deception Island, at 30 kilometers southwest of Hannah Pt. Chinstrap penguin colony in Vapour Col. belongs to a managed site (ASMA 4 Management Plan 2012) with scientific only access, both are situated at the South Shetland Islands. Ronge Island (64ºS) is ca. 100 Km. south of them and situated at the Danco Coast, Northern Antarctic Peninsula.

In the case of Adelie penguin (*Pygoscelis adeliae* Hombron & Jacquinot) the protected colony of Avian I. was compared with the Jalour colony, which is surrounded but a permanent station. Avian Island (66ºS) is a protected area (ASPA 12X Management Plan) with limited human access to a comparatively big colony of adelie penguin (35600 breeding pairs). Oppositely Jalour Island (65º S) is a medium size colony (5558 breeding pairs) that has in its vicinity a permanent station.

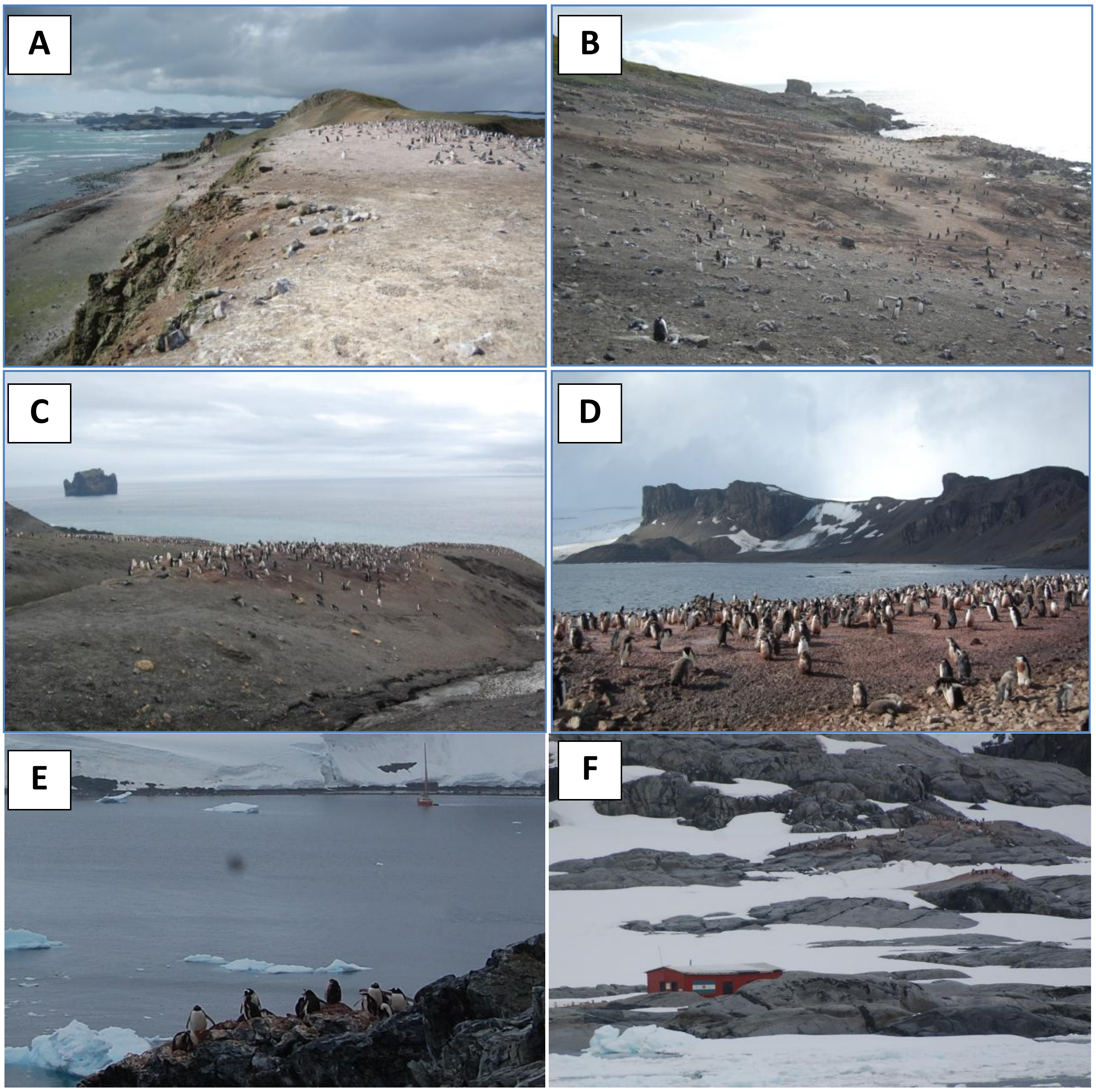

Fig. 1 Detail of locations. A) Papua colony at Devils Pt. (Livingston I.) B) Papua colony at Hannah Pt. (Livingston I.) C) Chinstrap colony at Vapour Col (Deception I.) D) Chinstrap inset colony at Hannah Pt. (Livingston I.) E) Papua colony at Ronge I with ship traffic backwards F) Adelie colony at Jalour I. close to an Argentinean depot .

Surveying and sampling

Samples were taken from mature individuals resting on the coast. Sexes were determined from blood samples. Table 1 summarizes the list of collected samples.

Table 1. Summary of collected samples by site, species, year and sexes

Colony	**Species**	**Year**	**Females**	**Males**	**Total**
Byers	Papua	2009	8	9	17
Hannah	Papua	2009	8	9	17
Hannah	Papua	2010	14	9	16
Ronge	Papua	2010	7	9	23
Total	**Papua**	**2009/2010**	**37**	**36**	**73**
Hannah	Chinstrap	2010	7	7	14
Ronge	Chinstrap	2010	18	5	23
Vapour	Chinstrap	2010	2	12	14
Total	**Chinstrap**	**2010**	**27**	**24**	**51**
Avian	Adelie	2010	15	8	23
Jalour	Adelie	2010	10	8	18
Total	**Adelie**	**2010**	**25**	**16**	**41**
Global	**All species**	**2009/2010**	**89**	**76**	**165**

Measurements of corticosterone levels

Penguin back feathers are relatively small compared to other birds, specially to those studies that use primary feathers. As a result the sampling unit cannot be a unique feather but a pool of those. In consequence the use of feather matter needs to be standardized. To this end a pool of 8-15 similar feathers from each individual was initially selected. Prior to the extraction the proximal part of these was removed, keeping the distal part containing most of the vane and barbs, this was made to homogenize the samples as some could contain longer vanes than others, even including parts of calamus. The processed cuts of feathers were prepared from enough feathers to weight more than 30 mg, which had previously been determined in a pilot study as sufficient for proper detection. The number of feathers required to reach this minimum varied from samples due to their variability. So to standardize the quantity of feathers used the final weight of the sample (mg) and combined length of feather cuts (mm) was measured after the preparations. The measure of both parameters as been previously used and compared (see Bortolotti *et al.* 2009). In our case this serve as a control system for the standardization of the sample natural heterogeneity and manipulation effects since as feather length grows, presumably weight increases at a given ratio. For this reasons the type of relationship is first explored through a scatter plot crossing the unit systems. Corticosterone was then extracted and analyzed for each individual (pool) of the colony and standardized by these measured parameters.

Methanol based extraction of corticosterone followed (Bortolloti *et al.* 2008). Feathers were submerged in tubes with 15 ml methanol. The samples were exposed for 30 minutes in a sonicating water bath at room temperature, followed by incubation for 24 hours at 50ºC in a shaking water bath. The methanol fraction was filtered to separate it from the solid residual. Methanol was then evaporated in a water bath at 50ºC in an extractor hood, which took 24 hours. After that, the remaining pellet was re-suspended in 500 µl PBS and stored frozen at -20ºC until corticosterone analysis. The amount of corticosterone in each sample was analyzed in a corticosterone ELISA of competition. Detection limits ranged from 37-75 to 5000-20000 pg. in one commercial kit (Arbor Designs Inc.). All samples were within these limits. Kit was previously validated (see Barbosa et al. 2013). Calibration curves were built for each reading based on known quantities from commercial CORT. Seven dilutions were made for calibration curves with values fitted to 98 % or superior accuracy.

Statistical analyses

Results were analyzed with the SPSS statistical package. Corticosterone data were analyzed both by feather weight (pg/mg) and by feather length employed (mg/ml). In each cases data were considered parametric and transformed by logarithm to be normalized. Data were explored through a general lineal model univariate. A few potential effects with known data were considered. First effect considered was the species itself (three groups: Papua, Adelie and Chinstrap). Secondly was the size of the colony, which was classified in three groups; small ones for those containing less than 1000 breeding pairs, medium ones holding in between 1000 and 10000 pairs, and big ones allocating more than 10000 pairs. In Papua species where data of one more year were present the effect of the season was also explored (two groups: 2009 and 2010). The effect of sex was also considered within colonies (either male or female). Effect of age or animal weight are not included as there are no available data but may be relevant to some extent. Finally the site itself is also considered (see above for site characteristics). Bonferroni multiple comparisons are carried out to detect possible differentiations between sites of the same species. Site differences can be due to several distinct features to be discussed. Among them can be named the distinct levels of human interference, the latitudinal changes or the local predator load.

Results

Correspondences between measure units in the response variable

Penguin back feathers have a natural variability in dimensions with a range of densities (in the sense of weight by length). These unit systems have a strong correlation with $r^2 = 0.89$ (see Fig. 2). The mean relationship was 0.56 mg per mm. Although either of them could be used as referential, the heterogeneity of samples still can conceal information (see Bortolotti et al. 2009). As such statistical analysis of effects were conducted for both unit systems, and the potential differences between their results discussed. We consider the use of the double way to serve also as a control system for the interpretations. Looking into the results we observe that Adelie penguin samples have more variability than the other species. For this reasons lesser correspondence in the results between the unit systems are expected for this species.

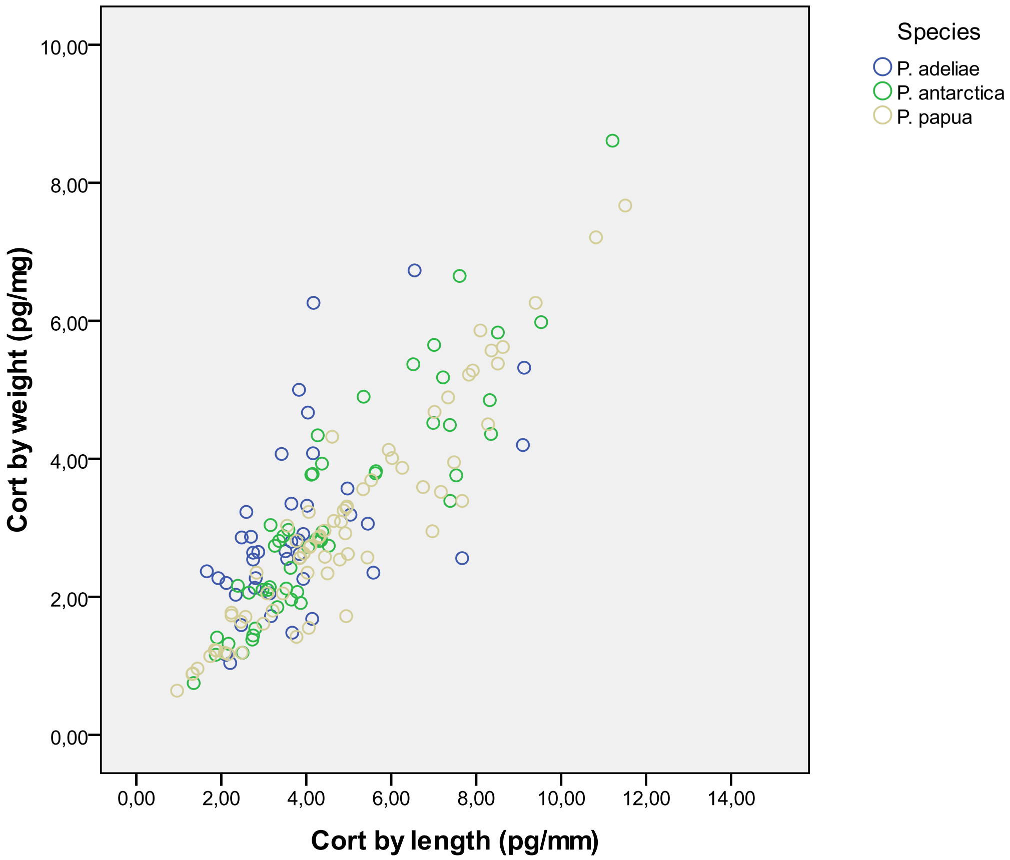

Fig. 2 Correspondence between feather weights (Y-axis) and feather lengths (X-axis). Data are segregated by species (colored circles in Green: Chinstrap penguin samples, in Blue: Adelie penguins´, and in Yellow: Papua penguins´).

Preliminary study of global effects

This exploratory study assess the co-effects of biological factors and their potential relevance when approaching to the comparison of colonies.

On data standardized by feathers weight (pg/mg) a general lineal model was applied considering the effects of species, site of the individuals. All effects (species p = 0.031, site p = 0.002) but sex (p = 0.313) are significant. On data standardized by feathers length (pg/mm) the same model was also applied. In this case the effects of species (p = 0.513) were not found significant. Site was still significant (p = 0.027) but now also marginally sex (p = 0.080).

In the case effect of species the lower levels were found in Adelie sp. Chinstrap had intermediate mean levels. Papua penguins had significantly higher levels than Adelie penguins. In the case of sex marginally mean higher levels of males were found than females. Table 2 summarizes the results.

Table 2. Results from the exploratory study of the biological co-effects (species and sex)

Units	Effect	p-valor	Levels	Values
By weight	Site	0.002*	See comparison by species	
(pg/mg)	Sex	0.313	Males	3.75
			Females	3.15
	Species	0.031*	Adelie	2.95*
			Chinstrap	3.45*
			Papua	3.68*
By length	Site	0.027*	See comparison by species	
(pg/mm)	Sex	0.080**	Males	5.73*
			Females	4.64*
	Species	0.513	Adelie	3.84
			Chinstrap	5.03
			Papua	5.95

*****Significant differences (95% confidence)
******Marginally significant differences (90%)

Since the species was a significant factor by weights the effect of site and size of the colonies will be explored independently for each species. Also as sex was found to have marginal effects by lengths it will be initially included in each of the analysis.

Site comparison by species: Papua penguin

A general lineal model was applied considering the effects of site, sex and year (see Results in Table 3). Byers is medium size colony with no human activities. Ronge island is a medium size colony with no direct human activity but ship traffic. Hannah Point is a medium size colony in a highly visited site.

On data standardized by feather weight the effect of the year is of very little significance (p = 0.867) and it is excluded from the advanced analyses. Sex is marginally significant (p = 0.095). Site is highly significant (p = 0.005). Significant differences by Bonferroni´s multiple comparisons are found between Byers and Hannah. On data standardized by feather length the effect of the year is also insignificant and removed. The potential effect of the sex is now less evident (p = 0.242). Site is also highly significant with p = 0.011. Multiple comparison show the same differentiation between Byers and Hannah.

Table 3. Results from site comparison between Papua colonies

Units	Effect	p-valor	Levels	Values
By weight	Year	0.867	2009	No Sig.
			2010	No Sig.
	Sex	0.095**	Males	4.15
			Females	3.22
(pg/mg)	Site	0.005*	Hannah*	2.80
			Ronge	3.79
			Byers*	5.24
By length	Sex	0.242	Males	No Sig.
			Females	No Sig.
(pg/mm)	Site	0.011*	Hannah*	4.37
			Ronge	6.87
			Byers*	7.82

*****Significant differences (95% confidence)
******Marginally significant differences (90%)

In Papua penguin the type of standardization has no variation, although effects are more evident expressed by weight. Differentiation between Byers and Hannah found by Barbosa et al. 2013 (data expressed by weights) maintains with inclusion of sexes and the new 2010 data from Hannah, both for data expressed by weights and lengths.

Site comparison by species: Chinstrap penguin

A general lineal model was applied considering the effects of site and sex (see Results on Table 4). Vapour col. is a big colony devoted to research activities. Ronge island is a small colony with no direct human activity but ship traffic. Hannah Point is a small colony within the visited one of Papua.

On cort. data standardized by feather weight the effect of sex is not significant (p = 0.731). Site is significant (p = 0.035). Differentiation between Hannah and Vapour is found by a Bonferroni multiple comparison. Several opposed variables related to these sites are to be discussed. On cort. data standardized by feather length the effect of sex is also no significant (p= 0.730). Site is in this case by little not significant (p = 0.101).

Table 4. Results from site comparison between Chinstrap colonies

Units	Effect	p-valor	Levels	Values
By weight	Sex	0.731	Males	No sig.
			Females	No sig.
(pg/mg)	Site	0.035*	Hannah*	4.25
			Ronge	4.10
			Vapour*	2.54
By length	Sex	0.730	Males	No sig.
			Females	No sig.
(pg/mm)	Site	0.101	Hannah	No sig.
			Ronge	No sig.
			Vapour	No sig.

*****Significant differences (95% confidence)
******Marginally significant differences (90%)

In the case of chinstrap penguin the use of weight or feather length does change significances. No effects are found significant by lengths, in the case of site this factor is rejected by little. Data by weights on Hannah Pt. samples (visited colony) are found higher than Vapour Col. (investigated colony).

Site comparison by species: Adelie penguin

A general lineal model was applied considering the effects of sex and site the colony (see Results on Table 5). Avian is an example of big colony with no human interference and Jalour of a small one with a scientific station nearby.

On cort. data standardized by weight the effect of sex is not significant (p = 0.541). The effect of site is also not significant (p= 0.234). On cort data standardized by feather length the effect of sex is significant (p = 0.025). The effect of the site is marginally significant (p = 0.092).

Table 5. Results from site comparison between Adelie colonies

Units	Effect	p-valor	Levels	Values
By weight	Sex	0.541	Males	No sig.
			Females	No sig.
(pg/mg)	Site	0.234	Avian	No sig.
			Jalour	No sig.
By length	Sex	0.025*	Males	4.61
			Females	3.28
(pg/mm)	Site	0.092**	Avian	3.58
			Yalour	4.31

*****Significant differences (95% confidence)
******Marginally significant differences (90%)

In Adelie penguin effects are explanatory on data by length whereas in data by weight there are no effects. Data of sites are marginally significant with higher levels in Yalour Island. Sexes also have different levels with higher levels in males than females, similarly to Papua penguin marginally results by weight.

Discussion

Test analyses

In the global analyses by using either weight or length the same variables are pondered but they have different levels of significance in each test. As no preferential system can be selected with clarity both ways are discussed. In any case a significant effect of the site is present in both as the main driver of effects. So to rule out non realist comparisons sites were analyzed by species.

In data by species results on Chinstrap and Papua are consistent either by weight or length, but with weight showing a higher evidence. In the case of Adelie a higher evidence is only found by feather length, whereas data by weight data are not clear. For these reasons data will be primarily discussed assuming effects significances by weight in Chinstrap and Papua and effects significances by length in Adelie. Nonetheless those alternative results with no observed effects will be also discussed.

Explanatory effects

Species was a relevant factor when analyzing the corticosterone levels, which lead us to think on different baseline levels among the three species. Papua penguins had the higher mean levels of CORT, and has been already identified as especially sensitive to human disturbance against chinstrap and Adelie penguins (Holmes 2007). Baseline corticosterone levels in feathers was higher in penguins from Devil’s Point, the protected rookery, than in Hannah Point, the place with intense tourist activity. Several studies have found an increase of baseline glucocorticoid levels in response to human disturbance (e.g. Wasser *et al.* 1997). However, other studies have found a reduction in the hormonal stress response after an induced stress situation (e.g. Walker *et al.* 2006, Villanueva *et al.* 2011) in magellanic penguins (*Spheniscus magellanicus*) from tourist areas in comparison with individuals from undisturbed areas. These authors suggested that these results showed a habituation of penguins to human visitation. Although direct comparison between results from CORT levels in feathers and plasma has to be taken with caution, our results are in accordance with those obtained by Walker *et al.* (2006) and Villanueva *et al.* (2011) although their study was conducted under a stress-induced situation. Habituation has also been found elsewhere in other animals exposed to tourism, such as Galapagos marine iguanas (*Amblyrhunchus cristatus*) (Romero & Wikelski 2002) or other human disturbances in blackbirds (*Turdus merula*) (Partecke *et al.* 2006). It has been suggested that a reduction in stress response is developed to avoid the negative effects of repeatedly elevated glucocorticoids (Sapolsky 1992) due to chronic stress. Whether reduced stress response in Gentoo penguins (or for the other species) is beneficial or detrimental is unknown, and some likely consequences, e.g., increase of egg or chick losses by predation, must still be tested.

Chinstrap penguin had intermediate levels, although these values are not significant and the animals may have a comparatively physiological behavior either to Papua´s or Adelie´s. As their values were closer to Papua´s we could expect more coincidences with Papua´s. Nonetheless, in this case CORT levels were found lower in the penguin rockery of Hannah Pt. with massive visits, in contrast to Papua´s. It must be argued than the colony of Chinstrap is much smaller and inserted in the Papua´s, being less exposed to pedastrian traffic. Also this values are lower to the huge colony of Vapour col. (with more than 35.000 breeding pairs), whereas the Papua´s ones were roughly of the same dimensions, being the size of the colony a feasible explanation. This goes in accordance with Ronge values, which is also a small colony and has similar values to Hannahs.

Other explanation could be the human activities in each site, in the case of Hannah this colony is not directly exposed to visitation, although animals still may deal with the associated ship traffic, this also occurs with Ronge´s which has Cuverville visited site in front of it but no direct visits, and a frequent traffic in the bay. In the case of Vapour there is no tourist visits but scientific visits (even some recreational) from the nearby stations are relatively frequent on the past two decades, in any case the numbers are much lower each time. However the interaction is much more intense with counting surveys on the rockeries, and animal captures with handling devoted to science. The potential impact of these studies is assumed in the benefit of the conservation outputs with a intense scientific production collected at a long set of publications (Barbosa et al. 1997, 2007, 2012a, 2012b, 2013). Still, the enormous size of the colony would support a minor impact (less than 1% of animals disturbed). The colonies of Hannah Pt. and Vapour have a short distance between them (30 Kilometers) and local meteorological factors are assumed to be equalized. In the case of prey hunting the colonies are close but not necessarily share the same waters. A rapid increase of whales´ sightseeing's has been observed on Hannah Pt (Pertierra, pers, observation) which would suppose a competence for krill feeding as one of the main sources for this species, but it is still to be identified any potential prey depletion. Finally, the predator pressure is differential between the two close colonies (Vapour and Hannah

Pt) as there is a documented leopard seal permanently installed in Vapour col. (Barbosa, pers. observation) which may be a more intense antagonic interaction responsible of chronic stress to these animals. For these reasons, it remains to be determined 1) whether scientific activities are explaining this low levels in investigated colonies, and so indicating an immune-depression in the shape of habituation to human presence, 2) whether there are any negative impacts from this, and 3) assess the conservation costs against the scientific benefits of research; as cases like this help to comprehend the effects of human interferences on a wider range of colony sites and human activities.

Adelia penguin samples showed higher levels in Yalour Islands colony than Avian Island. Yalour rockery is a medium size colony whereas Avian is a big one. In the case of Papuas´ the bigger colony (Byers) had higher levels, whereas in the case of Chinstraps´ the bigger (Vapour) had lower levels. With these trends size of the colony cannot be considered a key factor, more sites need to be to analyzed to increase confidence. In the case of human visitation Yalour has a close station whereas Avian is a protected site (ASPA 117), so the increased levels in Ýalour do not follow chronic habituation hypothesis suggested for the other species. Nonetheless a key factor could be hindering other effects, this is the geographical location. Whereas other species have at least some relatively close locations, in the case of Adelie colonies are separated for ca. 360 Km with Avian in a much southern position.

Differences in climate and meteorology can be driving these differences as the regime of temperatures affects the ratio of fasting (Vleck et al. 2000, Wingfield et al 1998) which in the case of Adelie teorically would have to be higher. This is confirmed by the results found (table 4). Significative differences were found in Adelia samples in comparison to the other species levels. While the biological conditions of the species could be the reason for this differentiation it must be pointed out that this species has not a northern location measured in our surveys, so these differences could be product of latitudinal changes. In this sense authors have regarded in regional studies the effect of latitude for other physiological parameters (Barbosa et al. 200X). However in the case of Papua and Chinstrap no differences where found between South Shetland Islands locations against Ronge Island (Danco Coast) covering a distance between approximately 220 and 250 Km. For these reasons we believe that Adelie differences are either a matter of location or alternatively species intrinsic features.

Sex can be considered a occluded factor that may produces differences. Males have been observed to have in some cases, marginally higher levels (Papua) and in others significant higher levels (Adelie). However in the case of Chinstrap´s samples there is no evidence at all. As the samples are in some cases unequal in the sexes ratio which can be correlating with site effects. For these reasons sexes differentiations are unclear, according to the literature… The importance of understanding this intrinsic feature comes when developing feathers as indicators for monitoring stress levels.

Finally we need to conclude with the limations of the study. The present analysis of the colonies surveyed are constrained by the limited number of sites and characteristic factors explored. We have no representative data for other effects such prey availability or colonies distance with same and between species, that are considered main features in the formation and existence of colonies (Fraser et al. 1992, Ainley et al. 1995), and thus not covered in this study. Also we have no regard to parasitic load or patogens, which may need to be accounted as they suppose a strong pressure to the animals (Barbosa et al. 2012b). For these reasons, and as the CORT levels in feather have discerned variations between sites and individuals, we support to reproduce and enlarge these studies.

We also would end by pointing out a practical consideration for studies of this type. Feather information can be explored as a tool for conservation as a direct monitoring. A systematic sampling for environmental management can be conducted by collecting feather pools from the ground, avoiding direct interaction with the animals and reducing the potential negative effects. However to this end validation studies need to be carried out. The problematic of this system is that no individuals information is obtained and biological aspects as sex are missing. In contrast the use of feather materials from the ground facilitate larger collections of samples, and the mixture of individual feathers that may come from different close animals at molting would serve as a wider source of samples, in the end producing a more complete measure of the colonies mean values. Yet are to see the effects of environmental detonation of samples, but in this sense Bortolotti (2009) found a large preservation of feathers in other birds. These approaches are to be explored in the study of marine birds of Antarctica in context of the environmental change.

Conclusions

CORT levels often showed differences between penguin colonies which lead us to think that differential elements are causing these variations. Feather length and weight were valid systems for standardization of samples having a strong relationship between them. However significance of results varied with the use of each, thus no preferential system is suggested but a crossed control. With our results, factors as human activities and sexes can be considered explanatory aspects. In the case of human activities our results follow the habituation hypothesis for Papua and Chinstrap penguin. In the case of sex, males have mean higher levels are found in the case of Adelia and marginally in Papua. Moreover other factors such size of the colonies, predator pressure, prey availability and geographic location are also potential explanatory variables but cannot be fully assessed in this study. Particularly a latitudinal effect can be regarded as a key aspect, as the differences between Adelia sites and comparing Adelia with other species could be explained by this feature. New studies are required to strengthen results and ascertain variables. As human interference may be one of the explanatory effects of different levels between colonies the precautionary principle should be applied. In areas with tourist visitation stay over the alert distances should be re-enforced and no new colonies should be visited to maintain them undisturbed from human presence. In summary, extraction of CORT deposited in feathers opens new approaches to the study of the marine birds of Antarctica.

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References

Ainley, D.G., Nur, N. & Woehler, E.J. (1995) Factors affecting the distribution and size of Pygoscelid penguin colonies in the Antarctic. *The Auk* **112**: 171-182.

Barbosa, A., Moreno, J., Potti, J. & Merino, S. (1997). Breeding Group Size, Nest Position and Breeding Success in the Chinstrap Penguin. *Polar Biology* **18**: 410-414.

Barbosa, A., Merino, S., Benzal, J., Martinez, J., & Garcia-Fraile, S. (2007). Geographic variation in the immunoglobulin levels in pygoscelid penguins. *Polar Biology*, *30*(2), 219-225.

Barbosa, A., Benzal, J., De Leon, A., & Moreno, J. (2012a). Population decline of chinstrap penguins (Pygoscelis antarctica) on Deception Island, South Shetlands, Antarctica. *Polar Biology*, *35*(9), 1453-1457.

Palacios, M. J., Valera, F., & Barbosa, A. (2012b). Experimental assessment of the effects of gastrointestinal parasites on offspring quality in chinstrap penguins (Pygoscelis antarctica). *Parasitology*, *139*(6), 819-824.

Barbosa, A., De Mas, E., Benzal, J., Diaz, J.I., Motas, M., Jerez, S., **Pertierra, RL.,** Benayas, J., Justel, A., Lauzurica, P., Garciapeña, F.J. & Serrano, T. (2013) Human Impact in Penguins: A comparison between a visited and a non-visted rookery. *Antarctic Science,* Aceptado 4 Jul 2012. doi:10.1017/S0954102012000739.

Beale, C. M., & Monaghan, P. (2004). Behavioural responses to human disturbance: a matter of choice? Animal Behaviour, 68, 1065-1069.

Beale 2007. The Behavioral Ecology of Disturbance Responses. International Journal of Comparative Psychology, 2007, 20, 111-120.

Bortolloti, G.R., Marchant, T.A., Blas, J. & German, T. 2008. Corticosterone in feathers is a long-term, integrated measure of avian stress physiology. *Functional Ecology*, **22**, 494–500.

Bortolotti, GR, Marchant, T, Blas J, & Cabezas S (2009) Tracking stress: localisation, deposition and stability of corticosterone in feathers The Journal of Experimental Biology 212, 1477-1482 doi:10.1242/jeb.022152

Buchert, L., & Vleck, C.M. 1998. Patterns of nest attendance and relief in Adelie Penguins, *Pygoscelis adeliae.* Antarctic *J.* United States 32: 103-104.

Braude, S., Tang-Martinez, Z. & Taylor, G.T. 1999. Stress, testosterone, and the immunoredistribution hypothesis. *Behavioral Ecology*, **10**, 345–350.

Bricher, P.K., Lucieer, A. & Woehler, W.J. 2008. Population trends of Adelie penguin (*Pygoscelis adeliae*) breeding colonies: a spatial analysis of the effect of snow accumulation and human activities. *Polar Biology*, **31**, 1397–1407.

Carlini, A.R., Coria, N.R., Santos, M.M., Libertelli, M.M. & Donini, G. 2007. Breeding success and population trends in Adelie penguins in areas with low and high levels of human disturbance. *Polar Biology*, **30**,917–924.

Chappelm, A. Morgana, KR & Bucher TL (1990) Weather, microclimate, and energy costs of thermoregulation for breeding Adelie Penguins. Oecologia 83:420-426.

Cobley, N.D. & Shears, J.R. 1999. Breeding performance of gentoo penguins (*Pygoscelis papua*) at a colony exposed to high levels of human disturbance. *Polar Biology*, **21**, 355–360.

Cockrem, J.F., Potter, M.A. & Candy, E.J. 2006 Corticosterone in relation to body mass in Adelie Penguins (Pygoscelis adeliae) affected by unusual sea ice conditions at Ross Island, Antarctica. General and Comparative Endocrinology 149, 244–252.

Cockrem, J.F., Potter, M.A. Barrett, D.P. & Candy, E.J. 2008 Corticosterone Responses to Capture and Restraint in Emperor and Adelie Penguins in Antarctica. Zoological Science 25, 291–298.

Cockrem, J.F., Barrett, D.P. Candy, E.J. & Potter, M.A. 2009 Corticosterone responses in birds: Individual variation and repeatability in Adelie penguins (Pygoscelis adeliae) and other species, and the use of power analysis to determine sample sizes. General and Comparative Endocrinology 163, 158–168

Cockrem, J.F., Potter, M.A. & Candy, E.J. 2006 Corticosterone in relation to body mass in Adelie Penguins (*Pygoscelis adeliae*) affected by unusual sea ice conditions at Ross Island, Antarctica. *General and Comparative Endocrinology* **149**, 244–252.

De Villiers, M. 2008. Review of recent research into the effects of human disturbance on wildlife in the Antarctic and sub-Antarctic region. *Working Paper 12, XXXI Antarctic Treaty Consultative Meeting, 2–13 June 2008, Kiev, Ukraine*.

Dharbar, F.S., Miller, A.H., Mcewen, B.S. & Spencer, R.L. 1995. Effects of stress on immune cell distribution: dynamics and hormonal mechanisms. *Journal of Immunology*, **154**, 5511–5527.

Ellenberg, U., Setiawan, N.A., Cree, A., Houston, D.M. & Seddon, P.J. 2007. Elevated hormonal stress response and reduced reproductive output in yellow-eye penguins exponsed to unregulated tourism. *General and Comparative Endocrinology*, **152**, 54–63.

Fairhurst GD, Frey MD, Reichert JF, Szelest I, Kelly DM, et al. (2011) Does Environmental Enrichment Reduce Stress? An Integrated Measure of Corticosterone from Feathers Provides a Novel Perspective. PLoS ONE 6(3): e17663. doi:10.1371/journal.pone.0017663

Fraser, W.R., Trivelpiece, W.Z., Ainley, D.G. & Trivelpiece S.G. (1992) Increases in Antarctic penguin populations: reduced competition with whales or a loss of sea

ice due to environmental warming? *Polar Biol.* **11**: 525–531.

Fraser, W.R. & Patterson, D.L. 1997. Human disturbance and long-term changes in Adelie penguin populations: a natural experiment at Palmer Station, Antarctic Peninsula. *In* Battaglia, B., Valencia, J. & Walton, D.W.H., *eds*. *Antarctic communities: species, structure and survival*. Cambridge: Cambridge University Press, 445–452.

Giese, M. 1996. Effects of human activity on Adelie penguin *Pygoscelis* 784 *adeliae* breeding success. *Biological Conservation*, **75**, 157–164.

Haykeyc, HJ. Samourg, M. Henderson, D. & Hart M.G. (1985) Haematological findings in captive Gentoo Penguins (Pygoscelis papua) with bumblefoot. Avian Pathol. 14:251-256.

Holberton, R.L., Helmuth, B. & Wingfield, J.C. 1996. The corticosterone stress response in gentoo and king penguins during the nonfasting period. *Condor*, **98**, 850–854.

Holmes, N. 2007. Comparing king, gentoo, and royal penguin responses to pedestrian visitation. *Journal of Wildlife Management*, **71**, 2575–2582.

Holmes, N., Giese, M., Achurch, H., Robinson, S. & Kriwoken, L.K. 2005. Behaviour and breeding success of gentoo penguins *Pygoscelis papua* in3 areas of low and high human activity. *Polar Biology*, **29**, 399–412.

Hood, L. Boersmaan L.D. & Wingfield J.C. 1998. The adrenocortical response to stress in incubating Magellanic Penguins (Spheniscus magellanicus). Auk 115:7&84.

IAATO (International Association for Antarctic Tour Operators). 2010. *IAATO overview of Antarctic tourism: 2009–10 season and preliminary estimates for 2010–11 and beyond*. http://image.zenn.net/replace/client/1000037/1000115/application/msword/ATCM33_ip113.doc , accessed August 2010.

Lattin, CR. Reed, MJ. DesRochers, DW. & Romero. ML. (2011) Elevated corticosterone in feathers correlates with corticosterone-induced decreased feather quality: a validation study. Journal of Avian Biology, 2011; 42 (3): 247 DOI: 10.1111/j.1600-048X.2010.05310.x

Le Mahoy Y, Karmand, H. Brioty, Handrich, R, Mioskorowsky E, Cherela, I. & Farni J. (1992) Stress in birds due to routine handlingand a technique to avoid it. Am. J. Physiol.263:R775-R78

Lynch, H.J., Fagan, W.F. & Naveen, R. 2010. Population trends and reproductive success at a frequently visited penguin colony on the western Antarctic Peninsula. *Polar Biology*, **33**, 493–503.

Metcheva, R., Yurukova, L., Teodorova, S. & Nikolova, E. 2006. The penguin feathers as bioindicator of Antarctica environmental state. *Science of the Total Environment*, **362**, 259–265.

Moreno, J., De Leon, A., Fargallo, J.A. & Moreno, E. 1998. Breeding time, health and immune response in the chinstrap penguin Pygoscelis antarctica. *Oecologia*, **115**, 312–319.

Naveen, R., Lynch, H.J., Forrest, S., Mueller, T. and Polito, M. (2012) First direct, site-wide penguin survey at Deception Island, Antarctica, suggests significant declines in breeding chinstrap penguins. Polar Biology 35(12), 1879-1888.

Otley, H.M. 2005. Nature-based tourism: experiences at Volunteer Point penguin colony in the Falkland Islands. *Marine Ornithology*, **33**, 181–187.

Partecke, J., Schwabl, I. & Gwinner, E. 2006. Stress and the city: urbanization and its effects on the stress physiology in European blackbirds. *Ecology*, **87**, 1945–1952.

Saino, N., Suffritti, C., Martinelli, R., Rubolini, D. & Moller, A.P. 2003. Immune response covaries with corticosterone plasma levels under experimentally stressful conditions in nestling barn swallows (*Hirundo rustica*). *Behavioral Ecology*, **14**, 318–325.

Sapolsky, R.M. (1992) Neuroendocrinology of the stress response. *In* Becker, J.B., Breedlove, S.M. & Crews, D., *eds*. *Behavioural endocrinology*. Cambridge, MA: MIT Press, 287–324.

Tin, T., Fleming, Z.L., Hughes, K.A., Ainley, D.G., Convey, P., Moreno, C.A., Pfeiffer, S., Scott, J. & Snape, I. 2009. Impacts of local human activities on the Antarctic environment. *Antarctic Science*, 892 **21**, 3–33.

Trathan, P.N., Forcada, J., Atkison, R., Downie, R.H. & Shears, J.R. 2008. Population assessments of gentoo penguins (*Pygoscelis papua*) breeding at an important Antarctic tourist site, Goudier Island, Port Lockroy, Palmer Archipelago, Antarctica. *Biological Conservation*, 897 **141**, 3019–3028.

Villanueva, C., Walker, B.G. & Bertelloti, M. 2012. A matter of history: effects of tourist on physiology, behaviour and breeding parameters in Magellanic penguins (*Spheniscus magellanicus*) at two colonies in Argentina. *Journal of Ornithology*, **153**, 219–228.

Viblanc VA, Smith AD, Gineste B. & Groscolas R. (2012) Coping with continuous human disturbance in the wild: insights from penguin heart rate response to various stressors BMC Ecology 2012, 12:10 doi:10.1186/1472-6785-12-10 Published: 11 July 2012

Vleck CM, Eertalinoda, N. Lecka V. & Bucher TL (2002) Stress, corticosterone and heterophil to lymphocyte ratios in free living adelia penguins *The Condor* 102.392-400.

Vleck, CM., Bucher, TL. Reed, L. & Kristmundsdotiay (1999) Changes in reproductive hormones and body mass through the reproductive cycle in the AdClie Penguin (Pygoscelis adeliae), with associated data on courting-only individuals. Proc. Int. Ornithol. Congr. 22:1210-1223.

Walker, B.G., Boersma, P.D. & Wingfield, J.C. 2006. Habituation of adult magellanic penguins to human visitation as expressed through behavior and corticosterone secretion. *Conservation Biology*, **20**, 146–154.

Wingfield J.C. 1994. Modulation of the adrenocortical response to stress in birds, p. 520-528. In K. G. Davey, R. E. Peter, and S. S. Tobe *Eds*. Perspectives in comparative endocrinology. Natl. Research Council of Canada, Ottawa.

4.4 La gestión de áreas protegidas: sistema de permisos, número de visitas y prácticas de intercambio de información

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Resumen El sistema de Zonas Antárticas Especialmente Protegidas (ASPAs) representa el mayor nivel de protección de espacios dentro del área del Tratado Antártico. Para reducir los impactos ambientales acumulativos, los visitantes de las ASPAs deben cumplir las normas del plan de gestión del espacio protegido y ser provistos de un permiso otorgado por la autoridad nacional competente. Las delegaciones de los países firmantes del Protocolo de Protección Ambiental para el Tratado Antártico están obligados legalmente a intercambiar anualmente la información (1) del número de permisos otorgados para la siguiente temporada y (2) el número de visitas efectuadas a las ASPAs en la pasada temporada. En este estudio evaluamos la efectividad de los sistemas actuales de permisos e intercambio de información a través de examinar los datos aportados sobre visitas al repositorio del Tratado Antártico como Sistema de Intercambio de Información Ambiental entre las temporadas 2008/09 y 2010/11. Encontramos que las delegaciones han interpretado e implementado de manera inconsistente la legislación de áreas protegidas. Más aun, algunas delegaciones han incumplido sus obligaciones con el Protocolo al no facilitar información completa sobre sus visitas a ASPAs. Con la información disponible observamos como las estimaciones de ocupación de ASPAs varían notablemente entre regiones y según el objeto principal de protección. No obstante sin la información completa disgregada por delegaciones el uso de los datos de visita es poco efectivo para construir las prácticas de gestión generales y particulares. Se recomienda desde este estudio la mejora del aporte de información y la interpretación de los datos de visita para permitir una mejor coordinación y más efectiva gestión de las actividades realizadas en las ASPAs.

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Palabras clave: Tratado Antártico, Protocolo Medioambiental, Planes de Gestión, Sistema de Intercambio de Información Ambiental, Áreas Protegidas

Management of Antarctic Specially Protected Areas: permitting, visitation and information exchange practices

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Abstract: Antarctic Specially Protected Areas (ASPAs) represent the highest level of area protection within the Antarctic Treaty area. To reduce environmental impacts, ASPA visitors must comply with the Area's management plan and receive an entry permit from an appropriate national authority. Parties to the Protocol on Environmental Protection to the Antarctic Treaty are obliged to exchange information on: i) the number of permits allocated for the forthcoming season, and ii) the number of visits to ASPAs during the previous season. We assessed the effectiveness of current permitting and information exchange practices by examining ASPA visitation data supplied to the Antarctic Treaty System's Electronic Information Exchange System during 2008/09–2010/11. We found that Parties have interpreted and implemented the protected area legislation inconsistently. Furthermore, some Parties did not fulfil their obligations under the Protocol by failing to provide full information on ASPA visitation. Estimations suggested that the level of ASPA visitation varied with ASPA location and the main value being protected. However, without full disclosure by Parties, ASPA visitation data is of limited use for informing general and ASPA-specific environmental management practices. Improved provision and formal interpretation of ASPA visitation data are recommended to enable more co-ordinated and effective management of activities within ASPAs.

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Key words: ASPAs, Antarctic Treaty, Environmental Information Exchange System, environmental management, environmental protocol, permits

Introduction

Of all the Earth's continents, Antarctica is the least impacted by human activity. Antarctica has no permanent population, but in recent decades has experienced increased visitation by tourists and an expansion in the footprint of infrastructure to support scientific activities (http://iaato.org/tourism-statistics, accessed January 2012, COMNAP 2012). Impacts resulting from local human activity may include disruption of soils, plants and microbial communities by human trampling or vehicle use, disturbance of marine mammals and birds, potential introduction of non-native species (including microorganisms) into terrestrial and lacustrine environments, low level pollution, disturbance of lake sediments and disruption of habitat due to construction of temporary or permanent huts or camps (Tin *et al*. 2009, Hughes & Convey 2010, Hughes *et al*. 2011, Cowan *et al*. 2011).

The Antarctic Treaty Consultative Meeting (ATCM) gives effect to the principles of the Antarctic Treaty through the agreement, by consensus, of regulations and guidelines for the management of the Antarctic Treaty area. Recognising the susceptibility to human impacts of vulnerable sites and the usefulness of some locations for scientific research, the ATCM has had a mechanism for area protection within Antarctica, in some form or other, for over five decades (Bonner & Lewis Smith 1985, Lewis Smith 1994, Australia 2010, ATCM 2011). Nevertheless, the manner in which these mechanisms have operated and a general lack of strategic planning in their use has resulted in a protected area network that, in large part, does not provide adequate spatial protection of Antarctica's biodiversity or geodiversity (New Zealand 2009, SCAR 2012, Terauds *et al*. 2012).

Following the entry into force in 1998 of the Protocol on Environmental Protection to the Antarctic Treaty (also known as the Madrid or Environmental Protocol), Treaty Parties committed themselves to the comprehensive protection of the Antarctic environment, designating Antarctica as a '*natural reserve, devoted to peace and science*' (ATCP 1991). Under this Protocol, the highest level of environmental protection for a site within the Antarctic Treaty area is achieved through designation as an Antarctic Specially Protected Area (ASPA). According to Annex V to the Environmental Protocol, ASPAs were to be designated to protect '*outstanding environmental, scientific, historic, aesthetic or wilderness values, any combination of those values, or on-going or planned scientific research*'. For a proposed ASPA to become formally designated the proposal must be accompanied by a management plan. Normally, the Party that originally puts forward an area for consideration by the ATCM as an ASPA becomes the proponent or managing Party and is responsible for drafting and updating the associated management plan. Once designation of an ASPA is complete, entry to the Area is allowed only in accordance with a permit issued by an appropriate national authority. Annex V (Article 10) lays out legislation on exchange of information for protected areas and specifically that '*Parties shall make arrangement for:* (*a*) *collecting and exchanging records, including records of permits and reports of visits, including inspection visits, to Antarctic Specially Protected Areas……;* (*b*) *obtaining and exchanging information on any significant change or damage to any……Antarctic Specially Protected Area……; and* (*c*) *establishing common forms in which records and information shall be submitted by Parties…*'. To fulfil part (c), the 'Guide to the preparation of Management Plans for Antarctic Specially Protected Areas', adopted under Resolution 2 (1998) and updated under Resolution 2 (2011), contains as Appendix 2 the 'Antarctic Specially Protected Areas (ASPA) visit report form', which should be used to record activities undertaken in the ASPA.

Parties have different calls on their ASPA permitting systems, with some Parties permitting large numbers of tourist visits to historic ASPAs for education and outreach purposes, in line with the number and size of tourist operators subject to each Party's legislation. Furthermore, due to differences in national legislation, some Parties have the ability to allocate permits to citizens of other nations/Parties, while others allocate permits only to their own nationals.

Information exchange is a fundamental principle upon which the Antarctic Treaty was founded. Article III of the Treaty establishes that Parties must exchange information on plans for scientific programmes in Antarctica in order to promote international cooperation in scientific investigations. The information exchange system has evolved substantially since the required information was first specified in 1961 (Canberra, Recommendation ATCM I-6), notably with a standard form for annual exchange of information that was first agreed by Parties in 1975 (Oslo, Recommendation ATCM VIII-6).

Currently, information exchange concerning visits to Protected Areas is to be submitted as Pre-season Information, which describes planned activities in the forthcoming year (including name and number of Protected Area to be visited, number of people permitted to visit, date/period and purpose) and Annual Report information which gives an accurate update on information concerning visits to Protected Areas that was supplied in the Pre-season Information of the preceding year. Preferably, Pre-season Information is to be submitted by 1 October, and in any event no later than the start of the activities being reported, while Annual Reports must be submitted as early as possible after the end of the austral summer season, but in all cases before 1 October, with a reporting period of 1 April–31 March.

Collection of Annual Report information is considered essential if the Committee for Environmental Protection (CEP) is to carry out its functions as described in Article 12 of the Environmental Protocol, which includes the need for the CEP to provide advice and recommendations on the operation of the Antarctic Protected Area system, environmental impact assessment procedures and the means of minimising or mitigating environmental impacts of activities in the Antarctic Treaty area (CEP 2010, paragraphs 14–20). Pre-season information is to be submitted to allow '*other Parties to make use of this information when planning their own activities*' (Australia 2001). However, during the negotiations of the current information exchange requirements in 1998, some Parties were of the opinion that Pre-season Information was 'generally received too late to be useful and that consequently little, if any, information should be sought at this time' (Australia 2001). Nevertheless, the new format was accepted (Appendix 4 of the Final Report of the ATCM XXIV). At ATCM XXII (Tromsø 1998) it was noted that the existing information exchange system could benefit from revision and the use of web-based technology, which lead to an intersessional contact group (ICG) being formed to discuss the issue (United States 1998). The ICG report recommended that a central website be created to facilitate information exchange, and suggested revisions to the timing of information submission (Australia 2001). At the request of the ATCM (Stockholm, Decision ATCM XXVIII-10) the Antarctic Treaty Secretariat developed the web-based Electronic Information Exchange System (EIES), which began operation on 15 September 2008 with the collection of the Pre-season Information for the 2008/09 season. To further simplify electronic information exchange for Parties, the Antarctic Treaty Secretariat (ATS) has provided a facility for Parties to submit information in a spreadsheet form, which is subsequently entered into the EIES database by the Secretariat (ATS 2012).

Given the long and complex history of the Protected Area and Information Exchange systems in Antarctica, this paper aims to analyze the effectiveness of the information exchange practices for protecting from human impact the values for which ASPAs were designated. We examined Parties' implementation and interpretation of Annex V to the Environmental Protocol associated with permit allocation for entry to ASPAs and how effectively Parties were providing information on ASPA visitation to the EIES. We also present some examples of analyses that could be made if all Parties submitted information on ASPA visitation to the EIES to the standard required by the Environmental Protocol.

Materials and methods

All data were obtained from the ATS website between December 2011 and January 2012 (www.ats.aq). ASPA management plans were obtained from the ATS Protected

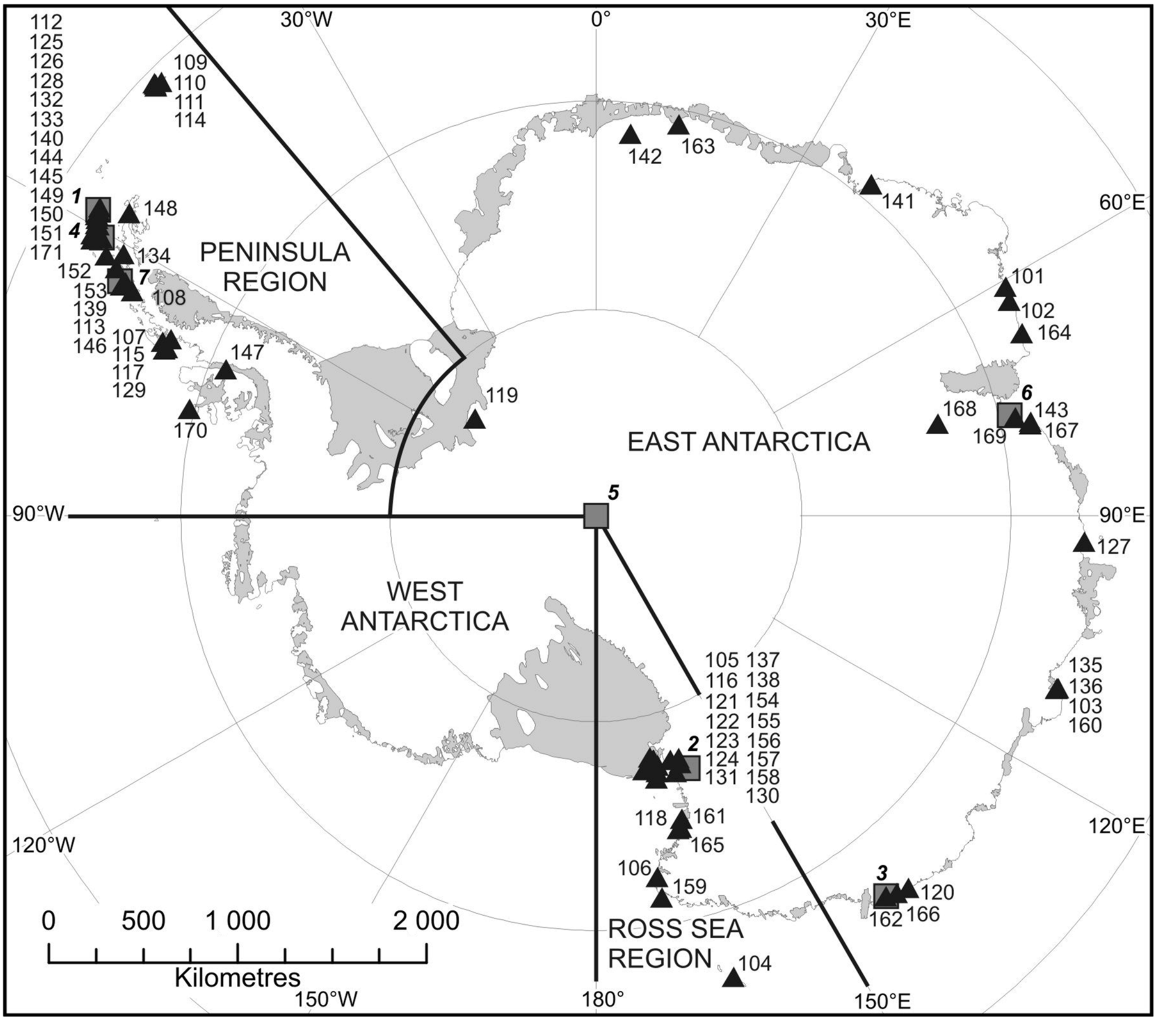

Fig. 1. Map of Antarctica showing the locations of the 71 Antarctic Specially Protected Areas (ASPAs) and seven Antarctic Specially Managed Areas (ASMAs) (correct as of December 2011). The four regions described in this research are shown.

Areas webpage (http://www.ats.aq/e/ep_protected.htm), while the Information Exchange web pages (http://www.ats.aq/e/ie.html), and in particular the EIES, were used to gather information on allocation of permits for entry to ASPAs. Relevant Antarctic ATCM and CEP Working and Information Papers were also accessed through the ATS website (http://www.ats.aq/devAS/ats_meetings.aspx?lang=e). An EIES function that summarises information on ASPA permitting, visitation and activities, available at: http://www.ats.aq/devAS/ie_reports.aspx?lang=e, was also used. Data available on the EIES as of December 2011 was used in this study. Any information added subsequently was not incorporated into the analysis.

ASPA designation and spatial distribution

Information relating to the designation date of each ASPA, and the proponent country was obtained from the Antarctic Treaty Systems document entitled 'Status of Antarctic Specially Protected Area and Antarctic Specially Managed Area Management Plans' (http://www.ats.aq/documents/ATCM34/WW/atcm34_ww003_e.pdf). Details of ASPA locations were taken from the ASPA management plans and the Antarctic Protected Areas Database (http://www.ats.aq/devPH/apa/ep_protected.aspx?lang=e).

Exchange of Pre-season Information and Annual Reports by Parties via the EIES

The Information Exchange data were examined to determine to what extent Parties had exchanged information via the EIES on activities they have conducted or authorised within the Antarctic Treaty area. The submission of Parties' Pre-season Information and Annual Reports to the EIES for the years 2008/09, 2009/10 and 2010/11 was examined. Electronic Information Exchange System submissions were included in the analysis, but internet links to external sources of information were not as often they were not functional, and were not managed by the ATS. Two Consultative Parties did not exchange any Pre-season Information or Annual Report documents for the period of study and therefore could not be included in this study.

Permit applications and ASPA visitation

To assess the effectiveness of implementation of the information exchange practices with regard to the ASPA system, we examined the allocation of permits for entry to ASPAs using the EIES database administered by the ATS. As the EIES was only formally recognized as the repository for this information in 2008/09, we focused on data submitted by Consultative Parties pertaining to the three years 2008–09, 2009–10 and 2010–11.

For each Party, the number of persons/visitors covered by permits was obtained from the Pre-season Information and the ASPA visitation details were taken from Annual Reports. In some cases the EIES included information on the period for which the permit was granted, however, this was not considered an accurate guide to how many days or hours were spent within the ASPA, as permits routinely cover considerably longer periods than is required by the applicant, to allow for often unavoidable changes in Antarctic logistics schedules that may delay access to the ASPA.

Permit applications and ASPA visitation were also examined from a regional perspective. For this analysis, the continent was divided into four regions: 1) the Antarctica Peninsula region, 2) the Ross Sea region, 3) the remainder of East Antarctica, and 4) West Antarctica, excluding the Antarctic Peninsula (Fig. 1). As before, for each ASPA, the number of permit applications was obtained from Pre-season Information and levels of visitation by Parties were recorded from Annual Report information. Acknowledging the lack of full ASPA visitation data we used the available information to: i) show the sort of analyses that could be possible if full data were available, and ii) look for trends in ASPA visitation, within the constraints imposed by the existing data (for years 2008–09, 2009–10 and 2010–11). The most reliable information on ASPA visitation was assumed to be contained within Annual Reports but, where Annual Report information was missing, we estimated the likely levels of visitation to each ASPA by examining the data available in the equivalent year's Pre-season Information or by extrapolating data from other Annual Report years. The following rules were used to make these estimations, in order of priority:

1) For Parties with one or two missing Annual Reports, but available Pre-season Information for: i) the missing year(s), and ii) the other years where Annual Reports are available, a ratio (or a mean of two ratios) of Annual Report/Pre-seasonal Information was applied to the available Pre-season Information figures to give an estimation of likely levels of ASPA visitation (applied to data from New Zealand, Spain, Germany, China).

2) For Parties where no Pre-season Information or Annual Report data is available for a given year or years, the mean of the available Annual Report information was used (applied to data from Australia, Brazil, Chile, Japan and the USA).

Where Parties exchanged information on topics other than protected area visitation via the EIES, but did not submit information on ASPA visitation, we assumed that no ASPAs were visited during the reporting period. Once estimated visit numbers for the three-year period were made, the mean estimated visitation levels per year were calculated. This value was used as a proxy for visitation levels in further analyses.

Concentration of visitors within ASPA ice-free areas

The research literature on local human impacts within Antarctica shows that values within ice-free areas of ASPAs may be at high risk from human visitation, although the sensitivity of ice-free ground and related values may vary between sites. It should be noted, however, that *c.* 10% of ASPAs containing ice-free ground may not be designated primarily to protect values directly linked with the ice-free area (e.g. historic values and some physical science values), while marine ASPAs may also be vulnerable to human impact, but tend to be larger in areas with research impacts potentially more dispersed. Nevertheless, *c.* 80% of ASPAs contain values linked with the ice-free ground.

For those ASPAs that contain ice-free ground, it was assumed that the majority of scientific research and field activities were undertaken on the ice-free ground and not on areas of permanent ice. To estimate the concentration of human activity on ice-free ground within ASPAs, the mean estimated visitation level per year was divided by the area

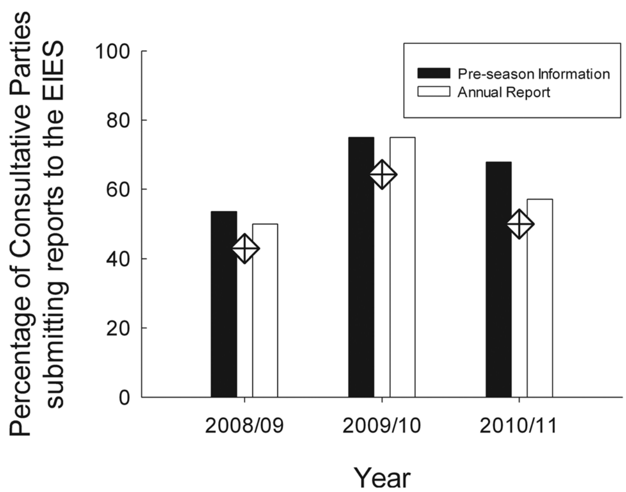

Fig. 2. Submission of information by Parties to the Electronic Information Exchange System between 2008/09 and 2010/11. Diamond symbols represent the percentage of Parties that submitted both Pre-season Information and Annual Reports for a given year.

Table I. Number of visitors covered by permits (Pre-season Information) and Antarctic Specially Protected Areas (ASPA) visitation details (Annual Reports) submitted by Antarctic Treaty Consultative Parties for the years 2008/09, 2009/10 and 2010/11[1]. Estimated mean number of permit applications requested in Pre-season Information and mean number of permitted ASPA visitors detailed in Annual Reports were calculated using the rule described in Materials and methods.

Party	Number of visitors covered by permit as detailed in the Pre-season Information report			Number of visitors to ASPAs under permit detailed in Annual Report			A: mean no. of permit applications requested in Pre-season Information	B: mean no. of permitted ASPA visitors detailed in Annual Report	Difference between A and B
	2008/09	2009/10	2010/11	2008/09	2009/10	2010/11			
USA	0	0	0	0	2319	2986	0.0	2652.5	2652.5
New Zealand	985	978	1098	x	83	x	1020.3	83.0	937.3
Australia	409	48	79	409	187	x	178.7	298.0	119.3
Brazil	x	46	89	x	0	53	67.5	26.5	41.0
Spain	66	98	67	x	99	x	77.0	99.0	22.0
Japan	0	0	6	x	14	13	2.0	13.5	11.5
UK	10	12	32	10	7	26	18.0	14.3	3.7
Uruguay	0	14	18	0	9	15	10.7	8.0	2.7
Italy	9	2	2	12	8	0	4.3	6.7	2.4
France	9	9	6	9	9	0	8.0	6.0	2.0
Chile	x	x	117	x	x	118	117.0	118.0	1.0
Norway	2	0	0	0	2	3	0.7	1.7	1.0
China	5	19	7	5	17	x	10.3	11.0	0.7
Germany	11	12	10	10	13	x	11.0	11.5	0.5
Rep. of Korea	0	0	0	0	0	0	0.0	0.0	0.0
Russian Federation	x	0	0	x	0	0	0.0	0.0	0.0
Netherlands	0	0	x	0	0	x	0.0	0.0	0.0
Belgium	0	x	x	0	0	0	0.0	0.0	0.0
Ecuador	0	x	0	0	x	0	0.0	0.0	0.0
South Africa	0	x	x	0	0	0	0.0	0.0	0.0
Sweden	x	x	0	x	0	0	0.0	0.0	0.0
Finland	x	0	x	x	0	0	0.0	0.0	0.0
Ukraine	x	x	0	x	0	x	0.0	0.0	0.0
Peru	x	0	x	x	0	x	0.0	0.0	0.0
India	x	x	x	x	x	0	x	0.0	x
Total	1506	1238	1531	455	2767	3214	1525.5	3349.7	3797.6[2]

x = No Pre-season Information or Annual Report present on the Information Exchange webpage as of December 2011.
0 = No permits applications or no details of permits and/or ASPA visitation included in Pre-season Information or Annual Reports.
[1] No Pre-season Information or Annual Reports were submitted by Argentina or Poland during the years 2008/09, 2009/10 and 2010/11 by December 2011.
[2] Total difference is the sum of the differences between A and B for each of the Parties.

Table II. Recorded and estimated visitation of Antarctic Specially Protected Areas (ASPAs) in the **a.** Antarctic Peninsula region, **b.** Ross Sea region and **c.** remainder of East Antarctica based on data in Pre-season Information and Annual Report submissions to the Antarctic Treaty System Electronic Information Exchange System. ASPAs were classified as follows: predominantly terrestrial ASPA with biological values (Terrestrial), geological values (Geological), terrestrial ASPA with physical values (Physical), historic ASPAs (Historical), commemorative ASPAs (Commemorative) and marine ASPAs (Marine).

a. Peninsula region.

ASPA No.	Classification	Visits recorded in Pre-season Information (2008/09–2010/11)	Visits recorded in Annual Reports (2008/09–2010/11)	Estimated no. of visits[1] (2008/09–2010/11)	Mean estimated no. of visits y^{-1}
128	Terrestrial	86	185	288.0	96.0
149	Terrestrial	8	137	207.5	69.2
150	Terrestrial	93	85	203.0	67.7
145	Marine	30	123	192.5	64.2
152	Marine	3	120	183.0	61.0
153	Marine	4	111	170.5	56.8
133	Terrestrial	16	62	112.5	37.5
126	Terrestrial	71	44	98.0	32.7
132	Terrestrial	19	60	95.5	31.8
140	Terrestrial	96	39	95.5	31.8
134	Terrestrial	17	60	91.5	30.5
151	Terrestrial	6	60	90.0	30.0
139	Terrestrial	4	49	77.5	25.8
125	Terrestrial	54	39	70.0	23.3
113	Terrestrial	4	35	56.5	18.8
117	Terrestrial	19	24	37.0	12.3
107	Terrestrial	2	21	31.5	10.5
112	Terrestrial	16	11	31.5	10.5
115	Terrestrial	2	19	27.5	9.2
148	Geological	7	8	22.5	7.5
129	Terrestrial	18	19	19.5	6.5
144	Marine	9	4	10.5	3.5
108	Terrestrial	5	6	6.5	2.2
114	Terrestrial	2	4	6.0	2.0
147	Terrestrial	3	1	4.5	1.5
110	Terrestrial	12	3	3.5	1.2
109	Terrestrial	2	2	2.0	0.7
146	Marine	0	1	1.5	0.5
111	Terrestrial	5	0	0.0	0.0
171	Terrestrial	2	0	0.0	0.0
170	Terrestrial	0	0	0.0	0.0
Total		615	1332	2235.5	745.2

b. Ross Sea region.

ASPA No.	Classification	Visits listed in Pre-season Information (2008/09–2010/11)	Visits listed in Annual Reports (2008/09–2010/11)	Estimated no. of visits (2008/09–2010/11)	Mean estimated no. of visits y^{-1}
158	Historical	717	1731	2629.6	876.5
155	Historical	919	870	1333.7	444.6
157	Historical	723	597	934.0	311.3
106	Terrestrial	29	242	365.2	121.7
159	Historical	17	240	361.4	120.5
124	Terrestrial	22	170	256.2	85.4
121	Terrestrial	14	161	242.3	80.8
116	Terrestrial	9	68	101.0	33.7
122	Physical	560	49	94.2	31.4
154	Terrestrial	19	62	93.7	31.2
165	Terrestrial	0	63	91.0	30.3
105	Terrestrial	22	55	83.9	28.0
161	Marine	0	56	84.0	28.0
137	Terrestrial	0	33	49.5	16.5
130	Terrestrial	13	19	29.2	9.7
138	Terrestrial	6	18	27.3	9.1
123	Terrestrial	0	12	18.0	6.0
118	Terrestrial	13	13	13.0	4.3
131	Terrestrial	6	0	0.3	0.1
104	Terrestrial	0	0	0	0.0
(156)	Commemorative	0	0	0	0.0
Total		3089	4459	6807.5	2269.2

Table II. Continued

c. East Antarctica.

ASPA No.	Classification	Visits listed in Pre-season Information (2008/09–2010/11)	Visits listed in Annual Reports (2008/09–2010/11)	Estimated no. of visits (2008/09–2010/11)	Mean estimated no. of visits y^{-1}
162	Historical	391	501	751.5	250.5
135	Terrestrial	31	34	51.0	17.0
169	Terrestrial	42	23	33.5	11.2
136	Terrestrial	32	12	18.0	6.0
101	Terrestrial	16	12	18.0	6.0
120	Terrestrial	24	18	18.0	6.0
141	Terrestrial	6	27	14.5	4.8
102	Terrestrial	12	7	10.5	3.5
168	Geological	20	10	10.0	3.3
142	Terrestrial	2	5	5.0	1.7
103	Terrestrial	4	0	0.0	0.0
127	Terrestrial	0	0	0.0	0.0
143	Terrestrial	0	0	0.0	0.0
160	Terrestrial	0	0	0.0	0.0
119	Terrestrial	0	0	0.0	0.0
163	Terrestrial	0	0	0.0	0.0
164	Terrestrial	0	0	0.0	0.0
166	Historical	0	0	0.0	0.0
167	Terrestrial	0	0	0.0	0.0
Total		580	649	930	310

of ice-free ground within the ASPA. The EIES does not include details of levels of activity or visitation to specific sites within ASPAs. Therefore, this methodology does not account for high concentrations of human activity that may be focussed within a small number of locations within ASPAs. However, it should give an indication of concentration of activity within the ASPA overall. Details of the ice-free area of the ASPAs were taken from the ASPA management plans. In this work, we excluded marine ASPAs and those with no ice-free ground (ASPA Nos 137, 144, 145, 146, 152, 153, 162, and 163) and all non-visited ASPAs for the study period (ASPA Nos 103, 104, 111, 119, 127, 160, 164, 166, 167, 170, and 171).

Number of Parties visiting specific ASPAs and the proportion of ASPA visitation by proponent Parties

Data on the number of Parties conducting or authorising visits to specific ASPAs within Annual Reports were obtained for the period 2008–09, 2009–10 and 2010–11. In this analysis, we excluded all non-visited ASPAs for the study period and Parties that did not visit any ASPAs.

In a subsequent analysis, the mean estimated visitation level of each ASPA over the period 2008/09–2010/11 was recorded for: i) the proponent Party (or Parties), and ii) the total visitation. The proportion of visitation to each ASPA by the proponent Party (or Parties) was calculated as a percentage of visitation by all Parties during the study period. Non-visited ASPAs were excluded from the study, as were ASPAs whose proponent did not provide any permit information (ASPA Nos 128, 132, 134, 163, and 171). Where an ASPA had two proponents (i.e. ASPA No. 133, Harmony Point), one of whom did not provide any permit information, only data from the proponent that provided information was included in the study.

Results

ASPA designation and spatial distribution

Figure 1 shows the location of the 19 ASPAs in East Antarctica (26.7%), 21 in the Ross Sea region (29.5%) and the 31 in the Antarctic Peninsula region (43.6%). No ASPAs have been designated in West Antarctica other than in the Antarctic Peninsula. The Antarctic Peninsula has the smallest area but largest number of ASPAs.

Provision of Pre-season Information and Annual Reports by Parties to the ATS

Figure 2 shows the level of information exchange by Consultative Parties between 2008/09 and 2010/11. In 2009/10, 75% of nations provided either Annual Reports or Pre-season Information, with 64% providing both. However, in the other two years examined, levels were lower with only 43% of Parties providing both documents in 2008/09.

Examination of the EIES data revealed several inconsistencies regarding provision of ASPA visitation data by Parties. 1) Some Parties submitted information on other aspects of their logistical activities to the EIES but did not report their ASPA visits. For example, one Party submitted no information concerning ASPA visits from

Table III. Number of visits per Antarctic Specially Protected Area (ASPA) type in different regions of Antarctica during the period 2008/09–2010/11 (three years).

ASPA type (main habitat or value protected)	Region: Antarctic Peninsula Estimated no. of visits	% for region	Ross Sea Estimated no. of visits	% for region	East Antarctic Estimated no. of visits	% for region	All Antarctica Estimated no. of visits	% for Antarctica
Historical	-	-	5258.7	77.2	751.5	80.8	6010.2	60.3
Terrestrial biological	1655.0	74.0	1370.6	20.2	168.5	18.1	3194.1	32.0
Marine	558.0	25.0	84.0	1.2	-	-	642.0	6.5
Geological	22.5	1.0	-	-	10.0	1.1	32.5	0.3
Physical	-	-	94.2	1.4	-	-	94.2	0.9
Commemorative	-	-	0	0	-	-	0	0
Total	2235.5		6807.5		930.0		9973	

2008/09–2010/11, but the management plan of an ASPA, for which it was the proponent, stated that penguin survey work was performed within the ASPA during the 2010/11 season (ASPA No. 127 Haswell Island), showing that at least one ASPA had been entered by that Party.

2) One Party submitted permit applications for a large number of ASPAs within the Pre-season Information, which were not visited subsequently.

3) The type of information provided to the EIES regarding ASPA visitation was not always consistent between Parties. For example, some Parties failed to specify the number of people to whom permits were granted to enter a specific ASPA, but rather list project numbers, or in one case failed to specify which ASPAs were visited at all.

4) A minority of Parties allocated permits to personnel on vessels transiting marine ASPAs, although this may have been considered unnecessary by other Parties due to the provisions relating to the right of passage across the high seas, stipulated within the United Nations Convention on the Law of the Sea (UNCLOS) and the Antarctic Treaty (Article VI).

5) Parties have demonstrated different interpretations of what constituted: i) acceptable environmental standards, and ii) a legitimate reasons for entry to an ASPA.

6) Parties have shown different approaches when allocating permits for entry to the nine ASPAs that are divided into sub-sites. Some Parties provided a permit for entry to all the sub-sites within an ASPA, irrespective of which needed to be visited, while other nations only gave permission to enter specific sub-sites within the ASPA.

7) Most Parties allocated permits for ASPA entry for periods of a few weeks or months within the reporting year, although one Party allocated permits that were valid for up to five years, and sometimes several years into the future.

Permit applications and ASPA visitation - by Parties

Table I shows the number of persons/visitors covered by permits (Pre-season Information) and ASPA visits (Annual Reports) submitted by Consultative Parties for

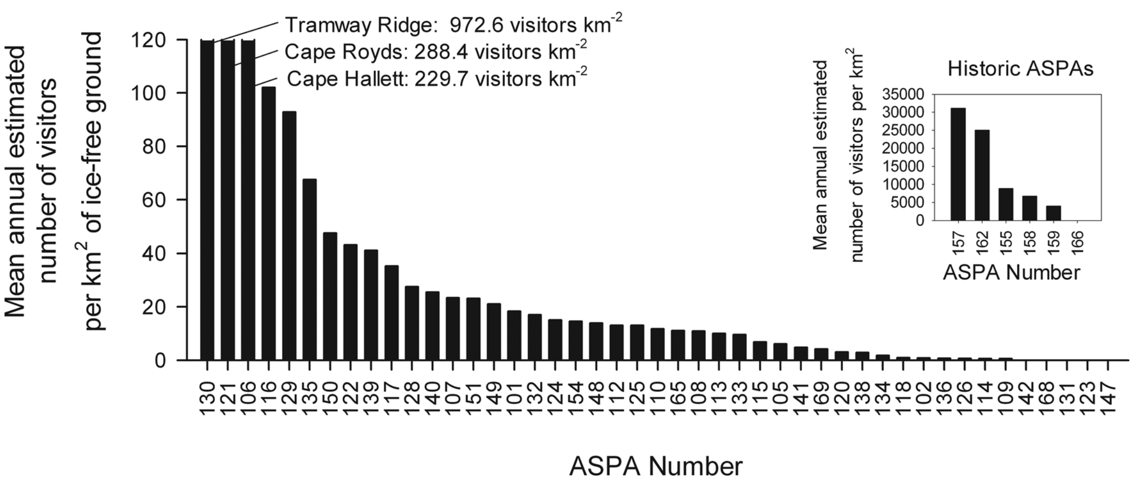

Fig. 3. Estimated mean annual number of visits per km^2 of ice-free ground within Antarctic Specially Protected Areas (ASPAs). ASPAs without ice-free ground and ASPAs that received no recorded visits during the study period were not included in the study.

the study years. These data indicate that more persons/visitors were covered by permits issued by the United States than all other Parties combined. Some Parties submitted no ASPA visitation data through the EIES during the period studied (Table I). Only 50% of Parties reported visiting ASPAs during the three year period examined.

Permit applications and ASPA visitation - by region

The number of protected areas, range of values under protection and levels of ASPA visitation differed greatly across the Antarctic Peninsula, Ross Sea and East Antarctic regions (Fig. 1, Tables II & III). Table II shows the estimated levels of visitation of ASPAs in the three regions containing ASPAs. For the 31 ASPAs in the Antarctic Peninsula region only three ASPAs were not visited (ASPA Nos 111, 170, and 171) while only two ASPAs out of 21 were not visited in the Ross Sea region (ASPA Nos 104 and 156) during the study period. However, in the remainder of East Antarctica, nine out of 19 ASPAs were not visited during the three year period (ASPA Nos 103, 119, 127, 143, 160, 163, 164, 166, and 167). The mean annual estimated number of individual visitors to ASPAs in Antarctica was 3324, with *c.* 23, 68 and 9% of visits to the Antarctic Peninsula, Ross Sea region and East Antarctica, respectively. The Ross Sea region had by far the greatest level of visitation, due to the concentration of highly visited historic sites within the region (i.e. four historic sites are included in the top five most visited ASPAs in the Ross Sea region) (Tables IIc & III). The estimated mean annual number of visitors to each ASPA within the Antarctic Peninsula region, Ross Sea region and the remainder of East Antarctica were 24, 108 and 17 individuals, respectively (estimated annual mean of 47 visits per ASPA across all of Antarctica, falling to 20 when visits to historic ASPAs are excluded).

Permit applications and ASPA visitation - by ASPA type

Over 60% of ASPA visitors went to historic ASPAs, predominantly in the Ross Sea region (Table IIb & c). Numbers of visitors to ASPAs protecting primarily terrestrial biological values was roughly similar in the Antarctic Peninsula (*c.* 1655 persons permitted) and Ross Sea regions (*c.* 1370 persons permitted), however, in the remainder of East Antarctica, numbers of visitors to terrestrial biological ASPAs was an order of magnitude smaller (*c.* 168 persons permitted; Table III). Overall visitors to East Antarctic ASPAs went predominantly to historic sites with, on average, less than 60 permits granted per year to enter all non-historical ASPAs. Only six ASPAs were designated to protect benthic habitats exclusively, with five of these in the Antarctic Peninsula region and one in the Ross Sea region. Around 6.5% of estimated visits during the study period were to the ASPAs protecting benthic marine environments (Table III). Across Antarctica, almost 20% of ASPAs were unvisited during the study period.

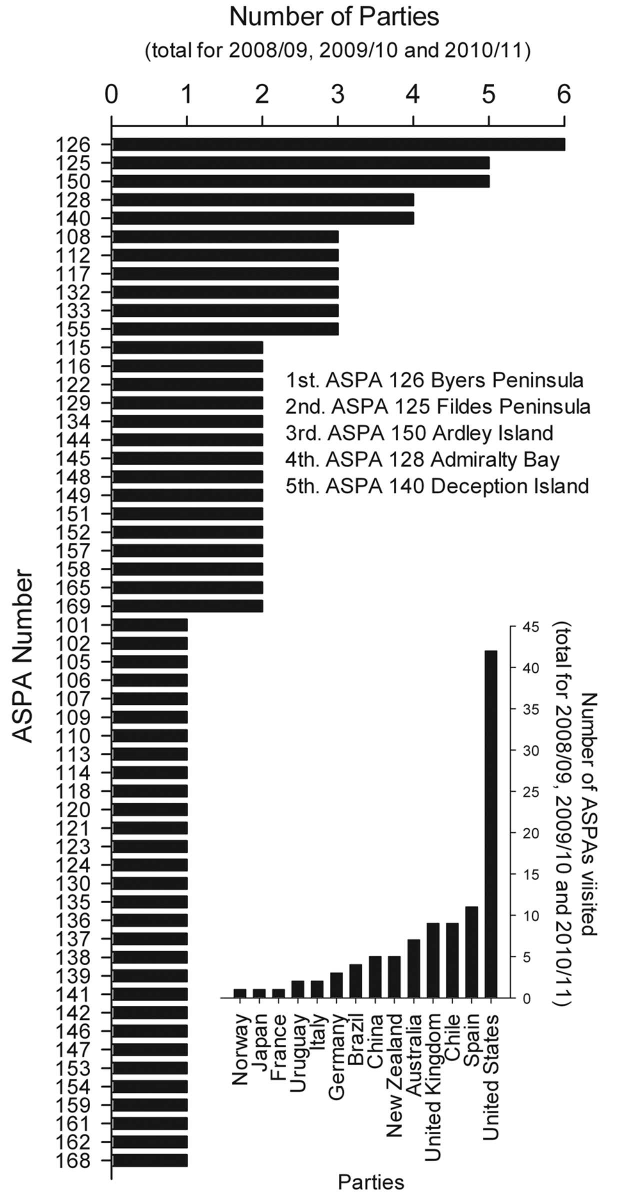

Fig. 4. Total number of Parties visiting each Antarctic Specially Protected Area (ASPA) during the study period. Inset: total number of ASPAs visited by each Party during the study period (Parties that did not visit ASPAs during the three seasons or did not provide any information during the study period are not shown).

Concentration of visitors within ASPA ice-free areas

The total area protected within ASPAs was *c.* 3361 km^2 and consisted of *c.* 1923 km^2 marine environment (57.2%),

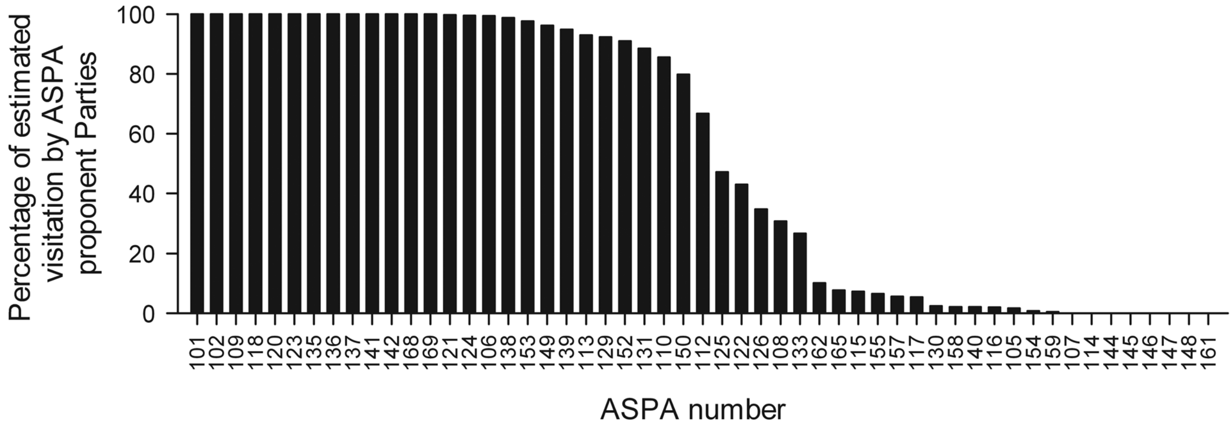

Fig. 5. Percentage of total estimated visitors to each Antarctic Specially Protected Area (ASPA) made by the proponent Party. Non-visited ASPAs were excluded from the study, as were ASPA whose proponent Party did not provide any permit information.

722 km^2 ice-free ground (21.5%), 633 km^2 permanent ice (18.8%) and 83 km^2 freshwater bodies (2.5%). Figure 3 shows the concentration of human visitation to ASPAs in terms of number of visitors per km^2 of ice-free ground. Some ASPAs were either small or contained little ice-free ground, and even low levels of visitation could produce extremely high annual estimated numbers of visitors per km^2 of ice-free ground. For example, while ASPA No. 130 Tramway Ridge, Mount Erebus, Ross Island has only a small area of ice-free ground, approximately ten visitors per year have resulted in the highest visitor concentration values, excluding those within the historic site ASPAs. In contrast, ASPA No. 126 Byers Peninsula (Livingston Island) and ASPA No. 123 Barwick and Balham valleys (south Victoria Land) contain substantial areas of ice-free ground, and consequently, visitor concentration values were low compared with other ASPAs. These examples reveal the different approaches to area protection within Antarctica: i.e. i) protection of generally small distinct features and values, or ii) large areas with many different features or multiple values. Nevertheless, at specific locations of interest within larger ASPAs the concentration of visitation may be as high as for smaller ASPAs. For example, despite ASPA No. 147 Ablation Valley and Ganymede Heights having an area of *c.* 180 km^2, human activity is focussed predominantly around three locations within the ASPA.

Number of Parties visiting specific ASPAs and the proportion of ASPA visitation by proponent Parties

Figure 4 shows that up to six Parties granted permits to enter the same ASPA over the three year study period (i.e. ASPA No. 126 Byers Peninsula). The five ASPAs visited by the highest number of Parties were all found in the South Shetland Islands, including three in the King George Island area. Some Parties that operate in the area did not submit ASPA visitation data, so the true numbers are almost certainly higher. Several Parties worked within the same ASPA for more than one season. The inset in Fig. 4 shows the number of different ASPAs visited by each Party during the study period, with the United States permitting visits to by far the most ASPAs (42 areas, or 59% of the total number).

Figure 5 shows the estimated level of visitation of ASPAs by proponent Parties. Personnel from proponent Parties made more that 90% of recorded visits in 43% of these ASPAs. For *c.* 80% of ASPAs, personnel from proponent Parties made at least one visit during the study period.

Discussion

Effectiveness of current information exchange and permitting practices

Following a SCAR/IUCN workshop on Antarctic protected areas in Cambridge, UK, in 1992, Penhale & Hofman (1994) made several recommendations to improve the implementation of the provisions of Annex V to the Environmental Protocol. In particular, they noted that: i) post fieldwork reporting is required detailing the activities carried out, changes or damage to special features in the Area and any observations of activities in the Area in contravention of the management plan, and ii) the exchange of information process needs to be improved. Twenty years on, these recommendations still need consideration and improved implementation (United States 1998; Fig. 2).

Some improvements in the level of information submission have been made since the introduction of the EIES and further improvements in the EIES were the topic of an ICG within the CEP during 2011/12 (ATS 2012). Nevertheless, technical difficulties alone do not explain the partial or complete lack of information exchange by some Parties. Two Parties submitted no information at all during our study period while others failed to provide ASPA permit/visitation data in both Pre-season Information and Annual Reports, despite their different intended purposes (see Table I). By failing to provide all of this information Parties did not fulfil their obligations under Annex V to the Environmental Protocol. Provision of this information is required, even if only to confirm that no ASPAs were visited by the Party in question. Furthermore, we found no reports from Parties detailing activities in contravention of the ASPA management plans, although such breaches have taken place (Braun *et al*. 2012).

Trends in ASPA visitation

The provision of ASPA visitation data was not sufficient for us to show actual levels of visitation and identify accurately areas at risk of cumulative impacts. Furthermore, the three-year period examined may not have captured adequately activities within the ASPAs required for the five-year review of the managements plans. We cannot predict when full, accurate and consistent disclosure of the ASPA visitation information by Parties will occur (ATS 2010, 2012). Until such times we will have to try to decipher any trends from the data available. The data presented in Tables II & III and Figs 3, 4 & 5 are, to differing degrees, based upon extrapolation of information provided by Parties within the EIES. Although careful consideration should be made before drawing conclusions for specific ASPAs, the data do reveal some general trends. For example, visitation of historic sites seem to make up the majority of ASPA visits (*c*. 60% of individual visits) with visits to ASPAs protecting terrestrial ecosystems making up around 32% of visits. Once visits to ASPAs protecting historic sites are excluded, levels of ASPA visitation within the East Antarctic were low (*c*. 60 per year) compared to the Antarctic Peninsula (*c*. 750 per year) and Ross Sea regions (*c*. 500 per year) (Table III). Clearly there is a wide variation in the number of visits each ASPA receives, with some of the remote or less accessible ASPAs receiving few, if any, visits over several years. Some Parties grant permits for visitors to enter a wider range of ASPAs than others, while, in most cases, the proponent Party for an ASPA permits a disproportionately large proportion of visits to the area.

At present there are no maximum limits on the number of people who can enter individual ASPAs (with the exception of some ASPAs protecting historic huts), or specific limits on the quantity of biological or geological samples that can be removed. Therefore, it may be useful to know which ASPAs stand out as potentially vulnerable to human impact and require: i) greater management effort to assess cumulative impacts, and ii) higher levels of co-ordinated field activity planning by interested Parties. When we compared ASPAs visited by three or more nations during 2008/09–2010/11 with ASPAs that received the highest concentration of visitors to ice-free ground we found that ASPA No. 150 Ardley Island, Maxwell Bay, ASPA No. 128 Western Shore of Admiralty Bay and ASPA No. 140 Parts of Deception Island received high levels of concentrated visitation from several different Parties. All three ASPAs are in the South Shetland Islands and may be at particular risk of impacts from visitation by multiple Parties, due to their close proximity to a high concentration of research stations.

The provision of Pre-season Information should, in theory at least, allow Parties to co-ordinate their activities to prevent over-visitation and potentially high levels of cumulative impact. However, it is not known to what extent the EIES is used by logistic co-ordinators when planning Antarctic fieldwork to ASPAs. Given that field party planning may occur several years in advance of the fieldwork, it is unclear if Pre-season Information exchange occurs early enough to permit changes in logistic planning within the ASPAs, as was raised when the concept was first discussed by the Treaty Parties. Personal contacts between different Parties and National Antarctic Programmes may be a more common route for information dissemination of this sort.

Conclusions

Our results show that some Parties are not fulfilling their obligations under the Environmental Protocol by failing to provide full information on protected area visitation. Furthermore, where information exchange does occur, it is still not undertaken consistently by all Parties. Clearly the collection of information on ASPA visitation is meaningless unless it is interpreted in a systematic way. Currently, Parties may see little point in spending time on submitting information that is little used, but at the same time our study has shown that it is difficult for ASPA visitation data to be interpreted meaningfully if the information is incomplete. To break this cycle, full and accurate information on ASPA visitation should be provided in an accessible format so that it can be interpreted and used to inform environmental management decisions. A function within the EIES, which allows users to generate automatically summarised information on ASPA permitting, visitation and activities undertaken within the ASPA, should make accessing the available information simpler.

In addition to EIES submissions, Parties are encouraged to forward information on activities conducted in the area (i.e. a copy of the ASPA visit report) to the ASPA proponent Party and it is recommended as a standard clause in most ASPA management plans (see Guide to the preparation of management plans for Antarctic Specially Protected Areas, www.ats.aq/documents/ATCM34/att/ATCM34_att004_e.doc). However, visit report exchange is undertaken routinely by few Parties, for example the

United Kingdom is the proponent Party for almost 20% of the ASPA network, but in a typically year will not receive any visit reports from other Parties. Furthermore, to assist ASPA proponents in revising the ASPA management plans and ensuring they are fit for their intended purpose, it would be advantageous if Parties working within each ASPA could provide full details on, for example: i) the types of scientific research undertaken, ii) any use of radio or stable isotopes, iii) the number of person days spent within the ASPA, and iv) for larger ASPAs, which parts were visited (including, if possible, coordinates and GPS tracks).

Finally, it may be helpful to review the usefulness of Pre-season Information concerning ASPA visits, given the short interval between the submission deadline (October) and the start of the Antarctic summer season (mid-October or earlier for some Parties' National Antarctic Programmes). If submission of Pre-season Information concerning ASPA visits was deemed no longer necessary Parties' information exchange obligations would become less onerous.

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References

ATCM (Antarctic Treaty Consultative Meeting). 2011. *Guidelines to the preparation of management plans for Antarctic Specially Protected Areas. Resolution 2* (*Annex*). http://www.ats.aq/devAS/ats_meetings_meeting_measure.aspx?lang=e.

ATCP (Antarctic Treaty Consultative Parties). 1991. *Protocol on Environmental Protection to the Antarctic Treaty.* http://www.ats.aq/documents/recatt%5Catt006_e.pdf.

ATS (Antarctic Treaty Secretariat). 2010. Electronic Information Exchange System (EIES): report on the 2nd operational season and summary information examples. *Secretariat Paper 9. Antarctic Treaty Consultative Meeting XXXIII Committee for Environmental Protection XIII. 3–14 May 2010, Punta del Este, Uruguay*.

ATS (Antarctic Treaty Secretariat). 2012. Report of the Informal Contact Group on the improvement of the EIES and other information exchange matters. *Secretariat Paper 10. Antarctic Treaty Consultative Meeting XXXV Committee for Environmental Protection XV. 11–20 June 2012, Hobart, Australia.*

Australia. 2001. Report from the Intersessional Contact Group reviewing information exchange requirements. *Working Paper 7. Antarctic Treaty Consultative Meeting XXIV Committee for Environmental Protection IV*. 9–20 July 2001, *St Petersburg, Russian Federation*.

Australia. 2010. Subsidiary Group on management plans - report on term of reference #4: improving management plans and the process for their intersessional review. *Working Paper 30. Antarctic Treaty Consultative Meeting XXXIII, Committee for Environmental Protection XIII. 3–14 May 2007, Punta del Este, Uruguay*.

Bonner, W.N. & Lewis Smith, R.I. 1985. *Conservation areas in Antarctica: a review prepared by the Subcommittee of Conservation of the Working Group on Biology*. Cambridge: SCAR/International Council of Scientific Unions, 299 pp.

Braun, C., Mustafa, O., Nordt, A., Pfeiffer, S. & Peter, H.-U. 2012. Environmental monitoring and management proposals for the Fildes Region (King George Island, Antarctica). *Polar Research*, 10.3402/polar.v31i0.18206.

CEP (Committee For Environmental Protection). 2010. *Report of the Committee for Environmental Protection* (*CEP XIII*). *Punta del Este, Uruguay, 3–7 May 2010*. http://www.ats.aq/documents/ATCM33/rp/atcm33_rp001_rev3_e.pdf.

COMNAP (Council Of Managers Of National Antarctic Programs). 2012. *Antarctic facilities*. https://www.comnap.aq/facilities.

Cowan, D.A., Chown, S.L., Convey, P., Tuffin, M., Hughes, K.A., Pointing, S. & Vincent, W.F. 2011. Non-indigenous microorganisms in the Antarctic - assessing the risks. *Trends in Microbiology*, **19**, 540–548.

Hughes, K.A. & Convey, P. 2010. The protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. *Global Environmental Change*, **20**, 96–112.

Hughes, K.A., Fretwell, P., Rae, J., Holmes, K. & Fleming, A. 2011. Untouched Antarctica: mapping a finite and diminishing environmental resource. *Antarctic Science*, **23**, 537–548.

Lewis Smith, R.I. 1994. The Antarctic Protected Area System. *In* Lewis Smith, R.I., Walton, D.W.H. & Dingwall, P.R., *eds. Developing the Antarctic Protected Area System*. Gland and Cambridge: IUCN, 15–26.

New Zealand. 2009. Updated analysis of representation of Annex V categories and Environmental Domains in the system of Antarctic Specially Protected and Managed Areas. *Working Paper 31 Antarctic Treaty Consultative Meeting XXXII Committee for Environmental Protection XII. 6–17 April 2009, Baltimore, United States*.

Penhale, P.A. & Hofman, R.J. 1994. The Antarctic Protected Area System. *In* Lewis Smith, R.I., Walton, D.W.H. & Dingwall, P.R., *eds. Developing the Antarctic Protected Area System*. Gland and Cambridge: IUCN, 57–60.

SCAR (Scientific Committee On Antarctic Research). 2010. Biodiversity-based evaluation of the Environmental Domains Analysis. *Working Paper 3 Antarctic Treaty Consultative Meeting XXXIII Committee for Environmental Protection XIII. 3–14 May 2010, Punta de Este, Uruguay*. Q3

Terauds, A., Chown, S., Morgan, F., Peat, H., Watts, D., Keys, H., Convey, P. & Bergstrom, D. 2012. Conservation biogeography of the Antarctic. *Diversity and Distributions*, **18**, 726–741.

Tin, T., Fleming, Z.L., Hughes, K.A., Ainley, D.G., Convey, P., Moreno, C.A., Pfeiffer, S., Scott, J. & Snape, I. 2009. Impacts of local human activities on the Antarctic environment. *Antarctic Science*, **21**, 3–33.

United States. 1998. Improving annual exchange of Antarctic information - facilitating information exchange. *Information Paper 28. Antarctic Treaty Consultative Meeting XXII, Committee for Environmental Protection I. 25 May 1998–05 June 1998, Tromsø, Norway*.

4.5 Gestión ambiental de un campamento científico en la Antártida Marítima: Conciliando los impactos de la investigación con los objetivos de conservación en las áreas libres de hielo

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Resumen Actualmente una proporción considerable de la investigación antártica se lleva a cabo a través del establecimiento de campamentos en el terreno, pero a menudo existe poca información detallada disponible sobre el funcionamiento de estas instalaciones. La ubicación remota de los campamentos y la fragilidad de los ecosistemas antárticos locales suponen un desafío para su gestión ambiental sostenible, con un bajo impacto ambiental de la investigación y la logística asociada. En el presente estudio examinamos la gestión ambiental del campamento español emplazado en la Zona Antártica Especialmente Protegida (ASPA) Nº 126 Península Byers, en la Isla Livingston, dentro del archipiélago de las Islas Shetland del Sur. En primer lugar se cuantifican los materiales desplazados y los residuos generados durante el periodo de 10 años de funcionamiento. El cálculo de emisiones de gases de efecto invernadero estima una media de 14 toneladas equivalentes de CO_2 generadas por investigador asociada al transporte de personal al sitio, a lo que se suman 44 toneladas equivalentes asociadas al transporte de materiales. En segundo lugar se registra la huella por pisoteo en la Península Byers, así como los demás impactos locales detectados. Los resultados muestran el patrón de movimiento dentro del ASPA y como las actividades e impactos se concentran en torno al campamento. A su vez se denotan los esfuerzos realizados para maximizar los beneficios científicos de las actividades de investigación. Finalmente a través de la experiencia se discuten recomendaciones practicas en las operaciones logísticas para minimizar los impactos y maximizar los beneficios científicos.

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Environmental management of a scientific field camp in Maritime Antarctica: reconciling research impacts with conservation goals in remote ice-free areas

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Abstract: Currently, a substantial proportion of Antarctic research is carried out through deployment of field camps, but little detailed information on the running of these facilities is often available. The remoteness of camps and the fragility of local Antarctic terrestrial ecosystems make the running of sustainable, low impact field science and logistics in ice free areas a challenge for environmental managers. In this study we examined the environmental management at the Spanish camp within Antarctic Specially Protected Area (ASPA) No. 126 Byers Peninsula, Livingston Island, South Shetland Islands. Firstly, the input of materials and generation of pollution associated with the camp during a ten year period of operation was quantified. Examination of greenhouse gas emissions shows a mean of 14 t CO_2 equivalent per researcher associated with transportation of people to the site, plus 44 t CO_2 equivalent per researcher, associated with transportation of cargo to the field site. Secondly, the cumulative trampling footprint across Byers Peninsula and associated local impacts were recorded. Results showed the pattern of human movement within the ASPA and how activities concentrated around the field camp site. At the same time every effort was taken to ensure scientific outputs from research activities within the ASPA were maximized. Practical recommendations on operational logistics are discussed to minimize environment impacts and optimize scientific benefits.

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Key words: carbon footprint, impact assessment, science, South Shetland Islands, terrestrial ecosystems

Introduction

Remote field camps are fundamental components of the terrestrial biological and geological research logistic programmes of many nations operating in Antarctica. Such field activities are bound by the legislation within the Protocol on Environmental Protection to the Antarctic Treaty which includes the mandatory assessment of environmental impacts associated with all activities within the Antarctic Treaty area. Remote field camps can be very different in nature, scale and spatial extent, but in each case the presence of researchers within field locations inevitably leads to some environmental impacts, which should be minimized to the maximum extent practicable. The Council of Managers of National Antarctic Programs (COMNAP) currently lists 81 research stations, 18 permanent or seasonal camps and two refuges within the Antarctic Treaty area (south of 60°S) (COMNAP 2012). Using these data, field camps represented only 17% of all reported facilities, but the level of human activity within temporary camps has been severely under-reported. For example, there has been a Spanish summer field camp on Byers Peninsula since 2001, which has not been included in the COMNAP list, yet in that time it must have generated at least some impacts. How 'transitory' these impacts may have been needs to be assessed; for example, the human activities may have lead to the development of paths and/or the introduction of non-native macro- and micro-biota, which may have longer term consequences for the area. The presence of temporary field camps established by two or more nations simultaneously at the same location may also have consequences for the environment and necessitate co-ordinated environmental management. For instance, a Chilean camp was simultaneously deployed during the 2010 season in Byers Peninsula beside the Spanish campsite, which led to additional environmental impacts in the local area (Fig. 1). Lack of information concerning the movement and activities of researchers from different nations may severely hamper the calculation of human footprint and cumulative impact of national operator activities within Antarctica. Some attempts have been made to establish the extent of human footprint over a wider spatial scale. Hughes *et al.* (2011) showed the location of UK field sampling activities since the late 1940s

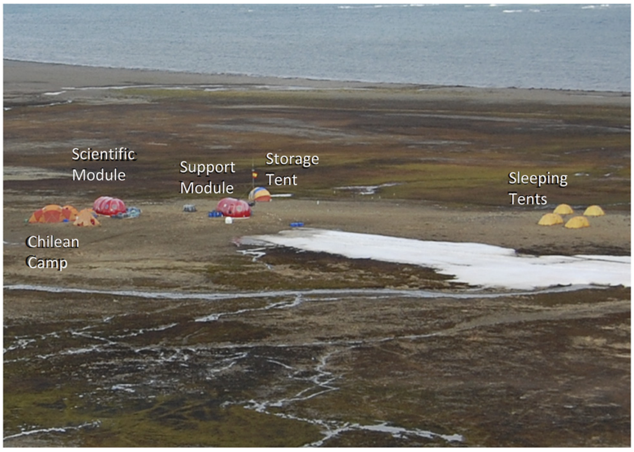

Fig. 1. View of the Spanish camp at South Beaches, Byers Peninsula. Picture taken on January 2010. Note that impacts associated with the Chilean camp are not included in this study.

and ice-free areas visited over much of the Antarctic Peninsula and beyond.

Levels of human occupation in field camps are generally much lower than on research stations. Typically, camps may contain from two to a dozen researchers compared with stations which can accommodate tens to several hundreds of personnel. However, field camps, although smaller and often more transient, may be considerably more numerous. Many stations act as staging posts to support field activities and temporary camps in remote locations. In many cases, the same biological and geological values that attract researchers and make necessary the temporary camps are also those values that are particularly vulnerable to human activity. Added to this, the remoteness of some field locations may generate logistical difficulties (Clarke *et al*. 2005) that make the maintenance of high environmental management standards problematic, e.g. ensuring waste is managed appropriately. Monitoring of long-term or cumulative impacts is rarely, if ever, routinely performed at field locations due to the transient nature of occupancy and the costs. Finally, re-use of camp facilities by subsequent expeditions may be irregular and closely linked with national funding of specific scientific topics for which the location is appropriate as a research site (whether this is geology, limnology, terrestrial biology, or more rarely a combination of scientific values).

In the case of field camps where the camp infrastructure is left *in situ* year-round the resulting impacts can be considered similar to bases although smaller in magnitude. Nevertheless, temporary camps still comprise most of the local impacts in remote areas. Described impacts in these areas include expansion of human footprint associated with land use and soil trampling (Campbell *et al*. 1998, Ayres *et al*. 2008, Tejedo *et al*. 2009), unintentional non-native species introduction (Frenot *et al*. 2005, Convey *et al*. 2006, Hughes & Convey 2010), wastes (Connor 2008) and soil pollution (Evans *et al*. 2000, Snape ~~et al.~~ 2002). Inevitably, scientific research activity has an environmental cost including disturbance of neighbouring fauna (Pfeiffer 2005, De Villiers *et al*. 2006, De Villiers 2008), damage to vegetation (Gremmen *et al*. 2003, Pertierra *et al*. 2013) and direct interference with biotic and abiotic components of the local ecosystem associated with scientific sampling. A review of the scientific knowledge on impacts can be found in Olech (1996) and Tin *et al*. (2009).

In this paper we study the human impact associated with the activities of the Spanish camp (Fig. 1) which primarily accommodated Limnopolar expeditions (2001–10) in the surrounding area on Byers Peninsula. Limnopolar group research was focused primarily on limnological studies on Byers Peninsula and so the Spanish programme established a field camp in a small vegetation-free area at the South Beaches in 2001. Furthermore, this facility has also accommodated other groups with scientific interests on Byers Peninsula, and thus facilitated a wider range of investigations than included in this analysis. Under the auspices of the International Polar Year (IPY, 2007–09) 31 researchers from seven nations participated in the 2008–09 field campaign, hosted by the Spanish programme. The field camp used at this time was later declared the designated campsite in the revised management plan for ASPA No. 126 (ATCM 2011) and declared an 'International Field Camp'.

Byers Peninsula is an extensive ice-free area in the western part of Livingston Island (South Shetland Islands, 62°34'35"–62°40'35"S, 60°54'14"–61°13'07"W). It contains numerous lakes, some of which formed comparatively recently, that have been the subject of extensive research by the Spanish Limnopolar research group since 2001. Byers Peninsula shows high biodiversity including breeding populations of elephant seals, gentoo penguin, giant petrels, skuas and other marine birds. Invertebrates include many species of collembola (springtails), acari (mites) and the dipterans *Belgica antarctica* Jacobs and *Parochlus steinenii* (Gerke). The vegetation is extremely diverse and abundant (Lindsay 1971), and includes Antarctica's only two native vascular plants (*Deschampsia antarctica* Desv. and *Colobanthus quitensis* (Kunth) Bartl.), around fifty moss species and over one hundred lichen species (ASPA No. 126 Management Plan, ATCM 2011). The peninsula also contains sites of geological interest and abandoned refuges and archaeological remains left by 19th century sealers (Smith & Simpson 1987). In recognition of the uniqueness and importance of Byers Peninsula it was originally designated as a Specially Protected Area (SPA) in 1966, a Site of Special Scientific Interest (SSSI) in 1975 and finally an Antarctic Specially Protected Area (ASPA No. 126) in 1991, with the most recent version of the area's management plan agreed by the Antarctic Treaty Consultative Meeting (ATCM) in 2011. ASPA designation is the highest level of area protection within Antarctica and includes a management plan which must be consulted and adhered to by all those authorized by appropriate national authorities to enter the protected area.

The natural and scientific values of Byers Peninsula have been the subject of many studies in addition to those carried out by the Spanish camp and have resulted in the establishment of some other field camps located mainly at coastal locations. Over the last decades, research groups from several Antarctic Treaty Parties have established field camps in other areas of Byers Peninsula, including expeditions from the United States, Argentina, Brazil, the United Kingdom, Chile and Spain. Although the camps were largely removed, it is still possible to identify the locations of some of these camps by the presence of litter/waste and disturbed ground. Away from the coast, scientists have left meteorological stations, sensors, plots, cairns and markers, some of which apparently are not maintained regularly and might, in effect, be abandoned. All expeditions that have been undertaken independently from the Spanish camp research in Byers Peninsula during the 2001–10 period have not been included in this assessment.

Field camps are important for Antarctic research, but little attempt has been made to monitor their impacts and often no record of their location is made available publically, making estimation of human footprint difficult. Intensity and spatial extent of local impacts are dictated by the number of visitors, how long they stay and where they go. These activities may accumulate over time to produce impacts that may be neither minor nor transitory, and may merit a higher level of environmental impact assessment such as an Initial Environmental Evaluation, as required in Annex I of the Environmental Protocol. Dedicated management measures are necessary to ensure the effective protection of the Antarctic environment. These include integral Environmental Impact Assessments (EIAs) with minimization, mitigation and monitoring of impacts (Bastmeijer & Roura 2007, Tin *et al*. 2009). The example of the Spanish camp is presented to guide others to evaluate and minimize their own impacts on Antarctic territories.

Materials and methods

To quantify the environmental costs associated with the running of the Spanish camp on Byers Peninsula we examined first the green house gas emissions of the transport and camp operation, the use of resources on the camp and the cumulative trampling pressure. Secondly, we estimated the Limnopolar programme's environmental impacts and examined the environmental management practices, based on available data. Finally, the scientific outputs resulting from the group's research at Byers Peninsula were listed.

Quantification of total carbon footprint for the field research camp on Byers Peninsula

Estimations of greenhouse gas emission per field researcher and per field season (2001/02 to 2009/10) were calculated. Total CO_2 equivalent emissions were considered under two headings: 1) direct transportation emissions (including aircraft transport of personnel to gateway ports in South America and transport of personnel by ship from South American ports) plus field camp accommodation and activities, and 2) indirect transport emissions associated with annual cargo transportation by ship from Spain.

Spanish Antarctic land-based research is focused predominantly on the South Shetland Islands. Thus, all researchers reach Antarctica by flying to gateway ports in South America and sailing to the Antarctic Peninsula. Researchers were assumed to have departed from the largest airport of their home country. Emissions derived from air transportation to gateway ports were calculated using the methodology of Amelung & Lamers (2007) and Farreny *et al*. (2011), where CO_2 equivalent emissions are obtained from fuel conversions. Punta Arenas (Chile) via Santiago was the main gateway port for air transport distance calculations. The alternative route of Ushuaia (Argentina) via Buenos Aires is roughly similar in total distance covered.

Data on oil consumption and total distance covered by the Oceanographic Research Vessel (BIO) *Las Palmas* were provided by the Spanish Navy. Distance covered was measured from: i) Spain to the South American gateway ports and back once per year (indirect costs), ii) from South American gateway ports to Antarctica, and iii) travel within the Antarctic Peninsula region (direct costs). This distinction was made to enable a comparison with direct emissions of other vessels.

Long distance cargo transportation and travelling costs for researchers from their home country were included in the CO_2 equivalent calculations. Emissions due to cargo were calculated based upon the return voyage from Cartagena in Spain to Punta Arenas in Chile, plus each season's return journeys to Antarctica for delivery of investigators, refuelling, resupply and waste disposal. As the ship also supported other scientists and stations in the area, emissions attributed to supporting science on Byers Peninsula were standardized and assigned proportionally.

CO_2-equivalent emission resulting from the camp activities was calculated based on fuel consumption according to International Panel on Climate Change conversion factor (Forster *et al*. 2007).

Quantification of field camp logistics, occupancy and trampling footprint

The site logistic and research activities were accounted and analysed in detail to establish and, where possible, quantify

Table I. Carbon emission directly associated with the Spanish field camp on Byers Peninsula.

Season	Season duration (d)	Number of people	Transportation emissions		Field camp fuel emissions	Total CO_2-Eq per season	Mean CO_2-Eq per researcher
			CO_2-Eq flights (t)	CO_2-Eq vessel (t)	CO_2-Eq (t)		
2001/02	74	11	21.21	132.17	0.8	154.18	14.02
2002/03	39	9	17.71	108.14	0.42	126.27	14.03
2003/04	59	7	13.87	84.11	0.63	98.61	14.09
2005/06	8	5	9.7	60.08	0.09	69.87	13.97
2006/07	83	14	23.48	168.21	0.89	192.58	13.76
2007/08	19	4	7.76	48.06	0.20	56.02	14.01
2008/09	82	31	63.86	372.47	0.88	437.21	14.10
2009/10	20	7	13.58	84.11	0.21	97.9	13.99
Mean	48	11	21.40	132.17	0.52	154.08	13.99
Total	384	88	171.17	1057.32	4.11	1232.6	

its potential cumulative environmental impact. Information was collected from the camp annual reports (including data on the daily occupation of the camp) while daily consumptions of camp resources, as well as occupation levels and research activities, were recorded systematically by the Principal Investigator (PI) of Limnopolar project who annually co-ordinated the use of the site.

Information on the routes travelled within Byers Peninsula was collected for the period 2001/02 to 2009/10. Data from 2007/08 season were not available, and no fieldwork was undertaken during 2004/05. Locations within the peninsula and distances between them were recorded using GPS (Garmin Model 60CSx). Information on the number of passes per route was first recorded through dairies from Limnopolar group field participants, but other research groups coincident in time with available recording of their walks in the PI diaries are also included in the calculations. We estimate that all tracks from more than 80% of Spanish camp hosts are incorporated in the analysis. Passes between the camp and the landing beach were estimated indirectly due to the high frequency of use, by multiplying number of occupants × days × four times (i.e. an average of four traverses was estimated for each person per day).

Analysis of local environmental impacts and management actions

Environmental pressures on the local ecosystems are next analysed with identification and status of impacts around the camp, trampling disturbances throughout the ASPA and all impact management efforts. Firstly, the provisions to protect the local values of the ecosystems contained in the ASPA No. 126 management plan were reviewed. This included legal obligations concerning environmental protection and management actions detailed in the Environmental Protocol, as well as the ASPA No. 126 Management Plan (ATCM 2011) that contains mandatory provisions put in place to safeguard the area's environmental values.

Identification of impact were based primarily upon provisions from the ASPA management plan, initial observations in the field and existing literature, taking into consideration minimization and mitigation of adopted measures, and monitoring programmes currently in place at the site. The status of impacts was obtained from either previous studies with specific monitoring or indirectly from field reports (such as wastes generated or potential introduction of species), and current calculations of

Table II. Carbon emission indirectly associated with the Spanish field camp on Byers Peninsula.

Season	Total researchers on SM *Las Palmas*	Number of people on Byers Peninsula	Percentage of total (%)	Cargo emissions CO_2-Eq (t)	Mean CO_2-Eq (t) per researcher
2001/02	50	11	22.00	528.26	48.02
2002/03	52	9	17.30	478.03	53.11
2003/04	59	7	8.42	327.69	46.81
2005/06	42	5	11.90	320.80	64.16
2006/07	67	14	20.89	577.13	41.22
2007/08	52	4	7.69	212.46	53.11
2008/09	115	31	26.95	744.53	24.01
2009/10	109	7	6.42	177.38	25.34
Mean	68	11	15.19	420.78	44.25
Total	546	88		3366.28	

pressures (such as CO_2 emissions, trampling footprint) combined with indicator studies. Minor impacts in the wider environment were also listed. To our knowledge no other impacts were associated with the camp in the ASPA.

The trampling disturbances in the ASPA were established according to the carrying capacities of representative terrestrial ecosystems. These have been previously determined by indicator studies: in the case of Tejedo *et al*. (2009) for soil fauna, where significant damages to open soils was observed after 200 passes, and for plant communities see Pertierra *et al*. (2013), where lower resistances were found on cryptogam communities. Therefore, the assessment of spatial pressures was based on current pressure intensities resulting from operational logistics in the camp and the trampling impacts around Byers Peninsula according to the previous thresholds.

Finally, the management actions to minimize potential environmental impacts on Byers Peninsula were evaluated at three levels: 1) minimization of the level of pressure on the environment, through the adoption of the precautionary principle (Cooney & Dickson 2005), 2) mitigation of emerging impacts, and 3) monitoring the ecosystems response to the impact effects.

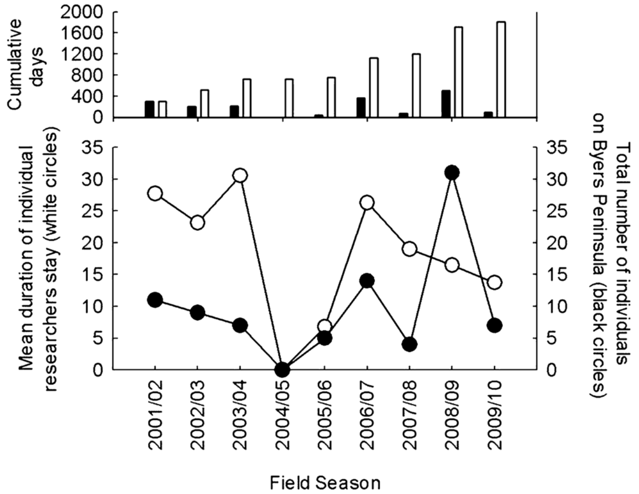

Fig. 2. Occupancy of the Spanish field camp on Byers Peninsula (2001–10). The top graph represents the cumulative number of days spent by researchers at the camp per season (black bars) and in total (white bars). In the bottom graph the white circles represent the mean duration in days of individual researchers at the camp each season. The black circles represent the total number of field researchers staying at the camp each season.

Results

Total carbon footprint supporting Byers Peninsula camp's field research

Results in Table I and II shows that most carbon emissions are associated with transport of personnel and cargo to the camp from Europe and South America. Personnel transport on ships generated an average of 14 t CO_2 equivalents per capita, similar to figures calculated for tourist ships. In contrast, indirect emissions calculated for cargo were around 44 t CO_2 equivalent per capita. To our knowledge there is no data available with which to compare this figure. Field emissions were minimal at less than one ton per year for the whole camp. Overall, the larger the number of researchers per season, the larger the emissions total. In general, CO_2 equivalent emission per individual researcher declined as the number of people in the camp increased, probably due to increased sharing of cargo and logistics. As most emissions were due to the transport of personnel and cargo to Antarctica, the duration of the field camp occupancy had little effect upon overall emissions each season, whilst transport had an increased effect.

Field camp logistics, occupancy and trampling footprint

The field camp opened on 5 December 2001. Since 2001, *c.* 15 000 kg of cargo have been transported by the BIO *Las Palmas* and transferred to the shore by inflatable boat and carried inland to the camp without use of land vehicles. The camp facilities comprise two plastic igloos (*c.* 10 m^2 each, one functioning as a laboratory and the other for living), one tent for storage and one tent for each individual person in the camp. The facility was assembled in two phases during November 2001 and November 2002. Once complete, the camp occupied 2592 m^2 on a raised beach in sandy ground, *c.* 110 m from the coast. Being relatively small the site made little visual impact in the local area (Summerson & Riddle 2000). Thus, the visual impact of Byers Peninsula camp is considered minimal due to the small-scale of the year-round camp facilities (igloo huts), although paths are also visible after surface snow has melted.

To date, the camp has been used for eight seasons (2001/02 to 2009/10, but excluding 2004/05 when the camp remained closed). The eight seasons allowed a total of 88 individual stays in the camp, with an average stay of 20.58 days per person. The cumulative number of person days spent on Byers Peninsula during the period 2001–10 is 1811 days (equivalent to five individual person years). Up to 31 researchers have stayed at the camp during any one season, with duration of their stay varying between 7 and 31 days. Researchers from 13 different nations have stayed there, particularly during the 2008–09 seasons when the camp was used by an IPY project. Persistent noise levels were limited to the generator. Figure 2 shows the level of occupancy of the camp since first established.

The 3.5 kW generator used an estimated 3.74 litres of oil per day. The generator was only used for scientific or domestic purposes and fuel consumption was independent of the number of researchers in the camp. To reduce waste and grey water production food was pre-cooked and frozen

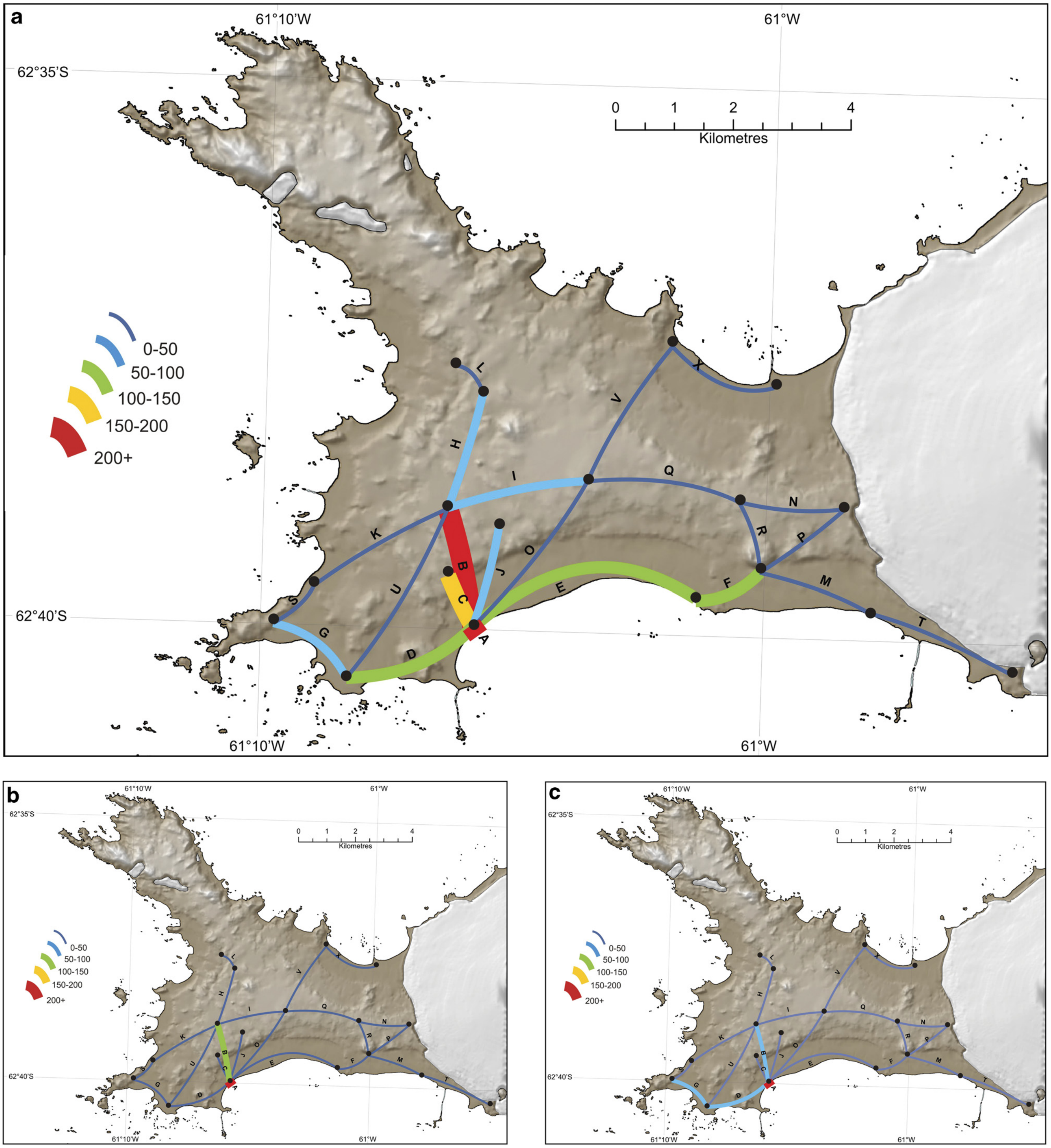

Fig. 3. Trampling footprint on Byers Peninsula of the Spanish Antarctic Programme 2001–10, excluding 2004/05 (no field season) and 2007/08 (no data). **a.** The distribution and cumulative number of estimated passes during the period of the camp. **b.** & **c.** The distribution and number of estimated passes during the International Polar Year (2008/09) and 2003/04 seasons, respectively.

in Juan Carlos I Spanish Station (< 40 km away) and sent to the camp with other cargo. Freshwater for cooking and cleaning was obtained from a nearby stream. The drinking water was hand-filtered through a small water purifier. Estimated water consumption was five litres per person per day and *c.* 5.5 m^3 in total for the camp during a typical season. To avoid contamination of the freshwater systems, human liquid waste was collected in plastic bottles and emptied into the sea below the low tide line. Human solid wastes were collected and sent into the waste streams on

Table III. Impact management for the Limnopolar expedition on Byers Peninsula. Impact management has been divided in three levels of action: i) minimization of the intensity of the pressure, ii) mitigation of the possible adverse impacts, and iii) monitoring of the environmental response.

Impact	i) Minimization of pressures	ii) Mitigation of impacts	iii) Monitoring of response
Soil and vegetation trampling	No more than eight people staying at the same time in the camp. Planned and co-ordinated field activities. Avoiding sensible biotopes.	Concentration in a field camp; concentration in frequented paths; dispersion in non-frequented.	Adverse effects in the camp area on soil physical properties and edaphic fauna. Recovery estimated inc. 3–5 years.
Species introduction	Bio-security procedures: dedicated clothing, decontamination of boots, and safety check-list for cargo.	Equipment cleaning measures implemented. Avoiding lake cross-contamination by use of different mouthpieces.	Non-native species introductions not detected. Systematic surveys.
Faunal disturbance	Minimization of light, noise and vibration from camp and expeditions. Avoiding bird and mammal concentrations (resting seals).	Precautionary distance procedures followed. Generator shut with no electric demand.	Impacts not detected. Not monitored but no unusual record.
Soil pollution	No dumping of any waste, use of sterile materials, avoiding the use of potentially dangerous products.	Field camp designed as a contention area with fast dispersion and renewal. Solid waste removed from the area and treated.	Sporadic surveys of soil pollution: organic pollutants and heavy metals.
Stream water contamination	Water supply from stream for drink and personal cleanliness use only. Purification based on tablets. Dry cleaning of materials with no use of washing products.	Separation of waste: storage of human solid waste. Urine stored and evacuated at sea. Other liquids stored and removed.	Water use quantified. Water quality not monitored due to zero residual output.

the ship to be managed with other rubbish. Camp rubbish was separated into organic and non-organic material and stored until it was shipped out. Waste consisted mostly of plastic packaging from food and laboratory materials. All bagged waste was shipped to South America for disposal whilst human waste was disposed of through a sewage waste treatment plant. No detailed record of the quantity of solid waste produced is available, but is estimated at around 450 kg for the period 2001–10. All chemical waste was stored in appropriate containers and disposed of through Universidad Autónoma de Madrid (Spain) facilities.

To estimate the trampling footprint on Byers Peninsula Fig. 3a shows the total number of passes recorded along each route between 2001 and 2010, with most recorded journeys to the landing beach (estimated as 6736 passes) and Limnopolar Lake (636 passes) where defined paths had developed. Limnopolar Lake was the main study site and the site of an automatic meteorological station. Other routes had fewer passes and in most cases, no visible tracks existed, so trampling was more diffuse. Figure 3b & c shows results for two individual years which represent different patterns of research. Figure 3b shows movements during a period of focused research by limnologists (2003/04), while Fig. 3c shows movements during a year of more diversified research activity (2008/09).

Local environmental impacts and management actions

Five main categories of environmental values were described for Byers Peninsula: 1) large areas of ice-free soils (López-Martínez *et al*. 1996, Navas *et al*. 2008), 2) extensive vegetation moss meadows and microbial mats (Lindsay 1971), 3) terrestrial (Tejedo *et al*. 2009) and 4) marine biodiversity, and 5) the unique concentration of freshwater bodies (Toro *et al*. 2007, Quesada *et al*. 2009).

These values were vulnerable to the following impacts: i) soil and vegetation trampling by researchers, ii) non-native species introduction to the area, particularly around areas of intense human activity, i.e. the camp and Limnopolar Lake, iii) disturbance of fauna around the camp and the landing beach, iv) pollution of soils around the camp, and v) contamination of freshwater bodies.

Trampling (Tejedo *et al*. 2009) was considered to be the greatest environmental pressure to the protected values due to the field activities of the researchers throughout the peninsula (see Table III & Fig. 3), although research has shown the terrestrial environment to be largely resilient to trampling over the past ten years, with recovery occurring within approximately five years if trampling is halted (Tejedo *et al*. in press). The movement of personnel and cargo into Byers Peninsula presented the opportunity for the introduction of non-native species (Frenot *et al*. 2005, Convey *et al*. 2006), but none were observed by biologists at the site, although no systematic survey was undertaken.

Human interaction with wildlife was kept to a minimum. The landing site contained large numbers of elephant seals, which were avoided to the maximum extent possible. Here a low interaction is expected to produce no disturbance according to Burton & Van den Hoff (2002). A petrel breeding colony located west of the camp was largely avoided as suggested by Pfeiffer (2005). Contact with marine mammals at the camp was rare as the camp was far enough inland to discourage animal visits. The penguin colony, located at Devils Point *c.* 5 km away, was visited rarely, following recommendations by Cobley & Shears (1999) and Holmes *et al*. (2008). Barbosa *et al*. (2013) documented Devils Point colony health as a reference location to other sites.

In the case of pollutants the release of fuel to the environment was limited to very small quantities discharged by the engines of inflatable boats during landings at the beach. No oil spills were reported in the camp area, and the possibility of minor spills during refuelling of the generator was minimized by using spill trays and oil absorbing mats. Water bodies were considered unaffected with no fuel spills reported in the stream near the camp or in the lakes. Air pollution was restricted to emissions from the generator. Cabrerizo *et al*. (2012) recorded soil pollution around the camp.

Management actions primarily focused on the impacts in the camp area, and developing trampling strategies around the peninsula. Table III shows the list of management actions and scientific data collected by researchers to reduce impacts by the Limnopolar expedition on Byers Peninsula.

Discussion

Global costs and logistics operations

In this study we have attempted to estimate the environmental pressures and likely impacts of ten years of research at a remote field camp on Byers Peninsula (Tables I & II). Greenhouse gas emissions are still a normal component of the environmental cost of research in remote areas, but are insignificant compared to greenhouse gas emissions globally and justified by the benefit Antarctic science has made to our understanding of global and regional climate change (Vaughan *et al*. 2003, Steig *et al*. 2009). Total carbon emissions are predominantly from transport showing similar values (*c.* 14 t CO_2 equivalent emissions) to those obtained for Antarctic tourism cruises (Farreny *et al*. 2011). Efforts to reduce fuel use and associated emissions have been made by COMNAP, although this may be driven by concerns over increases in the cost of fossil fuels, as well as for environmental reasons (Tin *et al*. 2009). Since most CO_2 is emitted during transport of cargo and personnel and very little with the actual running of the camp, science output might be enhanced with little increase in greenhouse emissions by increasing the duration of time at the field site. Nevertheless, this may have to be balanced against any increase in other, more local, environmental pressures and science requirements.

Given the vulnerability and uniqueness of Byers Peninsula, as recognized by its status as an ASPA, efforts should be focused on minimizing local environmental impacts. With this in mind the Spanish Camp was re-designated as an International Field Camp in 2010, making it available to scientist from other nations, and focusing impacts on this existing impacted site. Inevitably, the camp area has experienced cumulative impacts predominantly through trampling of the camp area. The igloo huts were made available for other scientists to use, following consultation with the Spanish Polar Committee.

Availability of information intended to reduce impacts

Anyone undertaking Antarctic research in Byers Peninsula ASPA (or any other Antarctic location) should look for guidance to help ensure environmental impacts are kept to a minimum. The Protocol on Environmental Protection to the Antarctic Treaty sets out minimum standards of environmental protection. Annex V of the Protocol provides guidance on Antarctic Protected Areas including ASPAs. Each ASPA has a management plan, which should set out mandatory and site-specific requirement to ensure a level of environmental protection but with no impact studies nor impact monitoring in the majority of ASPAs there is little information on the level of human impacts most ASPAs can withstand/recover from, and decisions on appropriate levels of human activity within ASPAs is generally guesswork, if considered at all. A lack of co-ordination between Parties makes implementation of any limits of human activity difficult if not impossible. During the revision of the Byers Peninsula ASPA Management Plan in 2010, undertaken by the United Kingdom, Spain and Chile, new strategies were developed to further improve environmental standards and minimize human impacts. These included the designation of the field camp as an International Field Camp, marking of visible paths to encourage the concentration of trampling impacts on ground disturbed already and designation of zones where access is restricted. A summary of human impact to that point was also included in the management plan.

Management of field activities and associated impacts

Earlier studies have shown that research on Byers Peninsula may result in potential impacts on the environment (Tejedo *et al*. 2009) but this should not compromise the qualities and characteristics of the site that make it of value (including scientific value) in the first instance. However, monitoring is required to ensure that the ecosystems are resilient, are not being damaged permanently, that human presence is below the carrying capacity for the location (Table III) and to identify any new activities that produce threats to the Antarctic environment. In the case of trampling management the SCAR Code of Conduct (2009) indicates one basic strategy: follow existing paths when necessary in order to avoid disturbing large areas. For this reasons two frequently used paths (to landing beach and to Limnopolar Lake) were defined. For Byers Peninsula, soil recovery rates from trampling impacts were considered acceptable (3–5 years; Tejedo *et al*. in press) although it is clear from Fig. 3 that the distribution and intensity of trampling impacts will vary depending upon the type and requirements of the science performed in any given year, (see Fig. 3b & c). Biosecurity measures were used to reduce the risk of non-native introductions, but given the rate of climate warming in the region and the level of visitation, Byers Peninsula may be particularly vulnerable to non-native species introductions (Hughes & Convey 2010, CEP 2011). Looking forward, a similar strategic use of the Byers Peninsula ASPA, including periods when some sites are not visited to allow recovery, may be appropriate. To date, a strategic management approach has been difficult to achieve as each nation operating in the area is acting independently and multi-party coordination of activities, in practice, has not occurred, despite this recommendation within the ASPA management plan. Given that human presence at the site is unlikely to cease, restrictions with higher standards could be applied in order to minimize environmental impacts and protect some zones for specific scientific purposes. To some extent, this has been done recently within the Byers Peninsula ASPA with the creation of two zones where access is restricted to those undertaking molecular and microbiological research with appropriately high quarantine standards (see http://www.ats.aq/documents/recatt/att474_e.pdf).

Optimization of science and outreach

Application of basic environmental standards, adequate management and appropriate knowledge of the resilience of the area to impacts can minimize the likelihood of irreversible impacts. Nonetheless impacts on the area are only permitted by research safeguarding the natural and scientific values in this protected area according to the management plan. Here, the isolation and pristine nature of the water bodies in Byers Peninsula make it an exceptional site for limnological research (Quesada *et al*. 2009). Scientists undertaking research in remote areas that could be considered pristine face the paradox that the research itself may cause environmental degradation at some level. It could be argued that only research attempting to answer the most critical science questions should be undertaken in such locations as their value for future science might be diminished (see Hughes *et al*. 2011). Although potentially controversial, the benefit of undertaking each science project in Antarctica may need to be balanced against the environmental impact and, in some cases, the irreversible change it may cause. For precautionary reasons all research activities in Antarctica should at least maximize the scientific benefits. In the case of the Limnopolar group every effort was made to publish data in peer-reviewed journals and to use this science to inform the revision of the ASPA management plan. Scientific outputs were also optimized by involving experts from a range of disciplines from other nations, particularly as part of the IPY. Finally, efforts were made to engage the general public in the work undertaken at the site and its key role for understanding the global change.

An important number of scientific publications including the work undertaken on Byers Peninsula through the Spanish camp (see Benayas *et al*. 2013) has been achieved between 2001 and 2010, including several high profile publications (López-Bueno *et al*. 2009, Kleinteich *et al*. 2012). In the case of the Limnopolar group there have also been six peer-reviewed chapters in scientific books, three non-peer review publications and several articles in popular science magazines. Scientific activity has also resulted in collection of long-term datasets characterizing lake water and meteorological parameters as well as viral biodiversity surveys, data on human impacts, microbial mat biodiversity surveys, and botanical, permafrost and climate studies. Research also contributed to the major revision of the ASPA management plan completed in 2011. Education has also been an important output of the Limnopolar expeditions to Byers Peninsula, including teaching of science associated with the area in several postgraduate courses and conferences and the training of several Masters and PhD students. Further publications using or building upon data already collected are expected in the coming years.

Conclusions

Experience at Byers Peninsula has highlighted the need for continuous environmental management of local impacts during field activities. Management should consider: i) pre-identifying possible impacts, ii) adapting logistical practices on a case by case basis, iii) monitoring activities and potential impacts, and iv) initiating specific environmental studies if considered necessary. Spanish scientists have undertaken precautionary monitoring and developed impact minimization strategies. For example, the route to Limnopolar Lake and to the field camp from the beach landing site were designated sacrificial paths to reduce wider impact. To avoid damages to vegetation, scientists were directed to walk on open soil areas instead of mosses, which however, produced disturbance to soil fauna which was consequently the subject of a further monitoring project.

Scientific results from the Spanish camp were exploited through international co-operation with initiatives such as the IPY and a diverse outreach. Operational activities focused on the allocation of other groups interested on Byers Peninsula to avoid as much as possible the duplication of logistics, also the camp facility was re-used as the international field camp. However, much more could be achieved in international coordination of activities. Scientific benefits in these sensitive areas need to be balanced against environmental impacts to safeguard their future scientific value

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References

Amelung, B. & Lamers, M. 2007. Estimating the greenhouse gas emissions from Antarctic tourism. *Tourism in Marine Environments*, **4**, 121–133.

ATCM (Antarctic Treaty Consultative Meeting). 2011. Management Plan for Antarctic Specially Protected Area No. 126 Byers Peninsula, Livingston Island, South Shetland Islands. Measure 4, *Report of the Thirty-fourth Antarctic Treaty Consultative Meeting*. Buenos Aires, Argentina. http://www.nsf.gov/od/opp/antarct/aca/nsf01151/aca2_spa126.pdf.

Ayres, E., Nkem, J.N., Wall, D.H., Adams, B.J., Barrett, J.E., Broos, E.J., Parsons, A.N., Powers, L.E., Simmons, B.L. & Virginia, R.A. 2008. Effects of human trampling on populations of soil fauna in the McMurdo Dry Valleys, Antarctica. *Conservation Biology*, **22**, 1544–1551.

Barbosa, A., Demas, E., Benzal, J., Diaz, J., Motas, M., Jerez, S., Pertierra, L.R., Benayas, J., Justel, A., Lauzurica, P., Garcia-Peña, F.J. & Serrano, T. 2013. Pollution and physiological variability in gentoo penguins at two rookeries with different levels of human visitation. *Antarctic Science*, **25**, 10.1017/S0954102012000739.

Bastmeijer, C.J. & Roura, R. 2007. Environmental impact assessment in Antarctica. *In* Bastmeijer, C.J. & Koivurova, T., *eds. Theory and practice of transboundary environmental impact assessment*. Leiden: Martinus Nijhoff, 175–219.

Benayas, J., Pertierra, L.R., Tejedo, P., Lara, F., Bermudez, O., Hughes, K.A. & Quesada, A. 2013. Review: scientific research trends within ASPA No. 126 Byers Peninsula. *Antarctic Science*, **25**, 10.1017/S09541020[redacted].

Burton, H. & van Den Hoff, J. 2002. Humans and the southern elephant seal. *Mirounga leonine. Australian Mammalogy*, **24**, 127–139.

Cabrerizo, A., Dachs, J., Barceló, D. & Jones, K.C. 2012. Influence of organic matter content and human activities on the occurrence of organic pollutants in Antarctic soils, lichens, grass, and mosses. *Environmental Science & Technology*, **46**, 1396–1405.

Campbell, I.B., Claridge, G.G.C. & Balks, M.R. 1998. Short and long-term impacts of human disturbance on snow-free surfaces in Antarctica. *Polar Record*, **34**, 15–24.

Clarke, A., Barnes, D.K.A. & Hodgson, D.A. 2005. How isolated is Antarctica? *Trends in Ecology and Evolution*, **20**, 1–3.

CEP (Committee For Environmental Protection). 2011. *Non-native species manual*. Secretariat of the Antarctic Treaty, 28 pp. http://ats.aq/documents/atcm34/ww/atcm34_ww004_e.pdf.

COMNAP (Council Of Managers of Antarctic National Programs). 2012. *List of Antarctic facilities*. https://www.comnap.aq/Members/Shared%20Documents/Antarctic_Facilities_List_1April2012.xls.

Connor, M.A. 2008. Wastewater treatment in Antarctica. *Polar Record*, **44**, 165–171.

Convey, P. 2008. Non-native species in Antarctic terrestrial and freshwater environments: presence, sources, impacts and predictions. *In* Rogan-Finnemore, M., *ed. Non-native species in the Antarctic Proceedings*. Christchurch: University of Canterbury, 97–130.

Convey, P., Frenot, F., Gremmen, N. & Bergstrom, D. 2006. Biological invasions. *In* Bergstrom, D.B., Convey, P. & Huiskes, A.H.L., *eds. Trends in Antarctic terrestrial and limnetic ecosystems. Antarctica as a global indicator*. Dordrecht: Springer, 193–220.

Cooney, R. & Dickson, B. 2005. *Biodiversity and the precautionary principle: risk and uncertainty in conservation and sustainable use*. London: Earthscan, 314 pp.

De Villiers, M. 2008. Review of recent research into the effects of human disturbance on wildlife in the Antarctic and sub-Antarctic region. *In* Human disturbance to wildlife in the broader Antarctic region: a review of findings. *Appendix 1, Working Paper 12 for XXXI Antarctic Treaty Consultative Meeting, Kiev, Ukraine, 2–13 June 2008*.

De Villiers, M., Bause, M., Giese, M. & Fourie, A. 2006. Hardly hardhearted: heart rate responses of incubating northern giant petrels (*Macronectes halli*) to human disturbance on sub-Antarctic Marion Island. *Polar Biology*, **29**, 717–720.

Farreny, R., Oliver-Solà, J., Lamers, M., Amelung, B., Gabarrell, X., Rieradevall, J., Boada, M. & Benayas, J. 2011. Carbon dioxide emissions of Antarctic tourism. *Antarctic Science*, **23**, 556–566.

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Nganga, J., Prinn, R., Raga, G., Schulz, M. & Van Dorland, R. 2007. Changes in atmospheric constituents and in radiative forcing. *In* Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. & Miller, H.L., *eds. Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, 129–234.

Frenot, Y., Chown, S.L., Whinam, J., Selkirk, P., Convey, P., Kotnicki, M. & Bergstrom, D. 2005. Biological invasions in the Antarctic: extent, impacts and implications. *Biological Reviews*, **80**, 45–72.

Gremmen, N.J.M., Smith, V.R. & van Torengen, O.F.R. 2003. Impact of trampling on the vegetation of sub-Antarctic Marion Island. *Arctic, Antarctic, and Alpine Research*, **35**, 442–446.

Holmes, N.D., Giese, M. & Kriwoken, L.K. 2008. Linking variation in penguin responses to pedestrian activity for best practise management on subantarctic Macquarie Island. *Polarforschung*, **77**, 7–15.

Hughes, K.A. & Convey, P. 2010. The protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. *Global Environmental Change*, **20**, 96–112.

Hughes, K.A., Fretwell, P., Rae, J., Holmes, K. & Fleming, A. 2011. Untouched Antarctica: mapping a finite and diminishing environmental resource. *Antarctic Science*, **23**, 537–548.

Kleinteich, J., Wood, S.A., Küpper, F.C., Camacho, A., Quesada, A., Frickley, T. & Dietrich, D.R. 2012. Temperature-related changes in polar cyanobacterial mat diversity and toxin production. *Nature Climate Change*, **2**, 356–360.

Lindsay, D.C. 1971. Vegetation of the South Shetland Islands. *British Antarctic Survey Bulletin*. No. 25, 59–83.

López-Bueno, A., Tamames, J., Velázquez, D., Moya, A., Quesada, A. & Alcami, A. 2009. High diversity of the viral community from an Antarctic lake. *Science*, **326**, 858–861.

López-Martínez, J., Martínez de Pisón, E., Serrano, E. & Arche, A. 1996. Geomorphological map of Byers Peninsula, Livingston Island. *In* López-Martínez, J., Thomson, M.R.A. & Thomson, J.W., *eds. Geomorphological map of Byers Peninsula, Livingston Island*. BAS GEOMAP series, sheet 5-a, 1:25 000, with supplementary text. Cambridge: British Antarctic Survey, 65 pp.

Navas, A., López-Martínez, J., Casas, J., Machín, J., Durán, J.J., Serrano, E., Cuchi, F. & Mink, S. 2008. Soil characteristics on varying lithological substrates in the South Shetland Islands, Maritime Antarctica. *Geoderma*, **144**, 123–139.

Olech, M. 1996. Human impact on terrestrial ecosystems in West Antarctica. *NIPR Symposium on Polar Biology, Proceedings*, **9**, 299–306.

Pertierra, L., Lara, F., Tejedo, P., Benayas, J. & Quesada, A. 2013. Rapid denudation processes in cryptogamic communities from Maritime Antarctica subjected to human trampling. *Antarctic Science*, **25**, 10.1017/S095410201200082X.

Pfeiffer, S. 2005. *Effects of human activities on southern giant petrels and skuas in the Antarctic.* PhD thesis, Ecology Institute, University of Jena. Available at: www.db-thueringen.de/servlets/derivateservlet/derivate-6345/Pfeiffer.pdf.

Quesada, A., Camacho, A., Rochera, C. & Velázquez, D. 2009. Byers Peninsula: a reference site for coastal, terrestrial and limnetic ecosystem studies in Maritime Antarctica. *Polar Science*, **3**, 181–187.

SCAR (Scientific Committee On Antarctic Research). 2009. *Environmental code of conduct for terrestrial scientific field research in Antarctica*. http://www.scar.org/researchgroups/lifescience/Code_of_Conduct_Jan09.pdf.

Smith, R.I.L. & Simpson, H.W. 1987. Early nineteenth century sealer refuges on Livingston Island, South Shetland Islands. *British Antarctic Bulletin*, No. 74. 49–72.

Snape, I. 2002. Contaminant dispersal and mitigation at Casey Station: an example of how applied geoscience research can reduce environmental risks in Antarctica. *Royal Society of New Zealand Bulletin*, No. 35, 641–648. Q3

Steig, E.J., Schneider, D.P., Rutherford, S.D., Mann, M.E., Comiso, J.C. & Shindell, D.T. 2009. Warming of the Antarctic ice sheet surface since the 1957 International Geophysical Year. *Nature*, **457**, 459–462.

Summerson, R. & Riddle, M.J. 2000. Assessing wilderness and aesthetic values in Antarctica. *In* Davison, W., Howard-Williams, C. & Broady, P., *eds. Antarctic ecosystems: models for wider ecological understanding*. Christchurch: Caxton Press, 303–307.

Tejedo, P., Justel, A., Benayas, J., Rico, E., Convey, P. & Quesada, A. 2009. Soil trampling in an Antarctic Specially Protected Area: tools to assess levels of human impact. *Antarctic Science*, **21**, 229–236.

Tejedo, P., Pertierra, L., Justel, A., Benayas, J., Convey, P. & Quesada, A. In press. Trampling on Maritime Antarctica: can soil ecosystems be effectively protected through existing codes of conduct? *Polar Research*.

Tin, T., Fleming, Z.L., Hughes, K.A., Ainley, D.G., Convey, P., Moreno, C.A., Pfeiffer, S., Scott, J. & Snape, I. 2009. Impacts of local human activities on the Antarctic environment. *Antarctic Science*, **21**, 3–33.

Toro, M., Camacho, A., Rochera, C., Rico, E., Bañón, M., Fernández-Valiente, E., Marco, E., Justel, A., Vincent, W.F., Avendaño, M.C., Ariosa, Y. & Quesada, A. 2007. Limnological characteristics of the freshwater ecosystems of Byers Peninsula, Livingston Island, in Maritime Antarctica. *Polar Biology*, **30**, 635–649.

Vaughan, D.G., Marshall, G.L., Connolley, W.L., Parkinson, C., Mulvaney, R., Hodgson, D.A., King, J.C., Pudsey, C.J. & Turner, J. 2003. Recent rapid regional climate warming on the Antarctic Peninsula. *Climatic Change*, **60**, 243–274.

4.6 Analizando el futuro de la Isla Decepción: estado actual, impulsores de cambio y políticas alternativas

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Resumen La Isla Decepción es un lugar único con un volcán activo inmerso en glaciares y cuya caldera está inundada, proporcionando el hábitat de comunidades biológicas muy poco frecuentes. Pero la Isla Decepción también tiene una larga historia de actividad humana, siendo actualmente uno de los sitios más visitados de la Antártida. En este lugar coexisten en muy poco espacio distintos valores naturales, científicos y turísticos y como resultado las distintas actividades asociadas interfieren entre sí, comprometiendo su futura conservación. Para minimizar los inevitables impactos resultantes y sus efectos acumulativos existen hoy distintos mecanismos reguladores de la isla bajo el marco del Tratado Antártico que ofrecen distintos niveles de protección. Esta isla es única además por ser gestionada colectivamente por seis programas nacionales y ha sido identificada como un ejemplo de zona administrada para la gestión ambiental de manera estratégica. Sin embargo, el éxito de las políticas de protección depende en gran medida del consenso de grupos con intereses. En este trabajo se recopilan los principales impactos ambientales y mecanismos reguladores en la isla, a la vez que se examinan las tendencias e impulsores de cambio actuales junto con los escenarios alternativos de gestión futura. En este trabajo se postula un juego de equilibrios entre intereses en los que distintas políticas intermedias puedan tener un papel clave para la sostenibilidad a largo plazo. Dos herramientas de gestión para este fin son propuestas: unos estándares de protección generales a través de directrices y protocolos básicos, y una limitación de accesos a las áreas vulnerables, basándose en capacidades de carga previamente identificadas. El éxito de estas políticas depende en gran medida de la información proporcionada por programas asociados de monitoreo ambiental. El desarrollo de esfuerzos adicionales de protección son esenciales para la conservación a largo plazo de la Isla Decepción, una de las mayores singularidades en la Antártida, cuyas condiciones particulares le hacen especialmente sensible a los efectos del cambio global.

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Enviado en Mayo 2011, Aceptado Marzo 2012

Palabras clave: Zona Antártica Especialmente Administrada, Gestión ambiental, Retos de conservación, Aceptación e Implementación

CHAPTER 8

LOOKING INTO THE FUTURE OF DECEPTION ISLAND: CURRENT STATUS, DRIVERS OF CHANGE AND POLICY ALTERNATIVES

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Abstract:

Deception Island is a unique place in the shape of an active volcano with a flooded caldera immersed in glaziers providing the niche to very rare biological assemblies. But Deception Island also has a long history of human activity, being currently one of the most visited locations in the Antarctic. Natural, scientific and tourist values coexist in a small area and thus some activities may interfere in others, compromising its future conservation. To minimize the inevitable resulting impacts and cumulative effects the existing regulatory mechanisms for the island under the Antarctic Treaty System (ATS) offer different levels of protection. This location is unique in being managed collectively by six countries, and has been identified as an exemplar of strategic environment management area. But the success of policies is high dependent on the general consensus. In this chapter, we provide a summary of environmental impacts, regulation mechanisms, as well as an examination of current trends, drivers for change and possible management scenarios. We describe a play of equilibriums where intermediate policy alternatives might have a key role for long-term sustainability. Two useful management tools for this aim are proposed: general standards of protection such as guidelines and protocols, and limited access on vulnerable areas based on carrying capacities. Success of these policies would rely in the information provided by monitoring programs. Additional efforts are essential for the long-term conservation of Deception Island, one of the most singular rarities in Antarctica whose unusual features make it especially vulnerable for global change effects.

Keywords: Antarctic Specially Protected Area – Environment – Management - Conservation

8.1 INTRODUCTION

Deception is a volcanic island within the South Shetland Islands at approximately 70 km from the Antarctic Peninsula. Its volcanic caldera is flooded and is connected to the Southern Ocean via a narrow channel, thus allowing marine access into the caldera / bay, known as Port Foster (Fig. 8.1). It has had a long history of human activity associated with sealing, whaling and scientific research and is currently one of the most visited tourist locations in Antarctica. With a surface area of 98.5 km2, Deception Island has unique and outstanding environmental, historic and scientific values. There are two active research stations and several monitoring stations. It is managed by the Antarctic Treaty parties under the Antarctic Treaty System. A Deception Island Antarctic Specially Managed Area (ASMA) Management Group, which comprises of six Antarctic Treaty parties, assumes the task of coordination of activities and facilitation of communication. The diversity of human activities taking place can result in potential conflicts between stakeholders and can also lead to pressures on the unique values of Deception Island. In this sense, Deception Island can be considered as a microcosm of the Antarctic where strategic management decisions need to be taken in order to accommodate competing priorities through consensus. In this chapter, we start by summarizing the present situation of the island: its human activities, regulatory mechanisms, values that are protected and environmental impacts. We then explore possible drivers of change and future regulatory scenarios. This roughly follows some of the components of the Millennium Ecosystem Assessment (MA). For the MA, a comprehensive framework was developed to analyze the effects of environmental change on ecosystems and human well-being at multiple geographic and time scales, while considering the interactions among individual natural resources and the consequences of the tradeoffs that are made in the decision-making process (Carpenter et al., 2009; Mooney et al., 2004). While Deception Island is a much simpler system than the global and sub-global regions where MA has been applied to, we believe that selected components of the MA framework can serve as a useful guide in an exploration of the future of Deception Island.

8.2 CURRENT STATUS

8.2.1 Historical development of human activities

The first humans to occupy the island were American and British fur sealers that arrived around 1820. Several Antarctic explorers, including Charcot and Bellingshausen also passed through on their expeditions (Martin 1996). Norwegian whalers arrived at the start of the 20th century, first basing their operations out of floating factory ships and later on from a land-based complex, of which remains still stands today at Whalers Bay (Dibbern 2010).

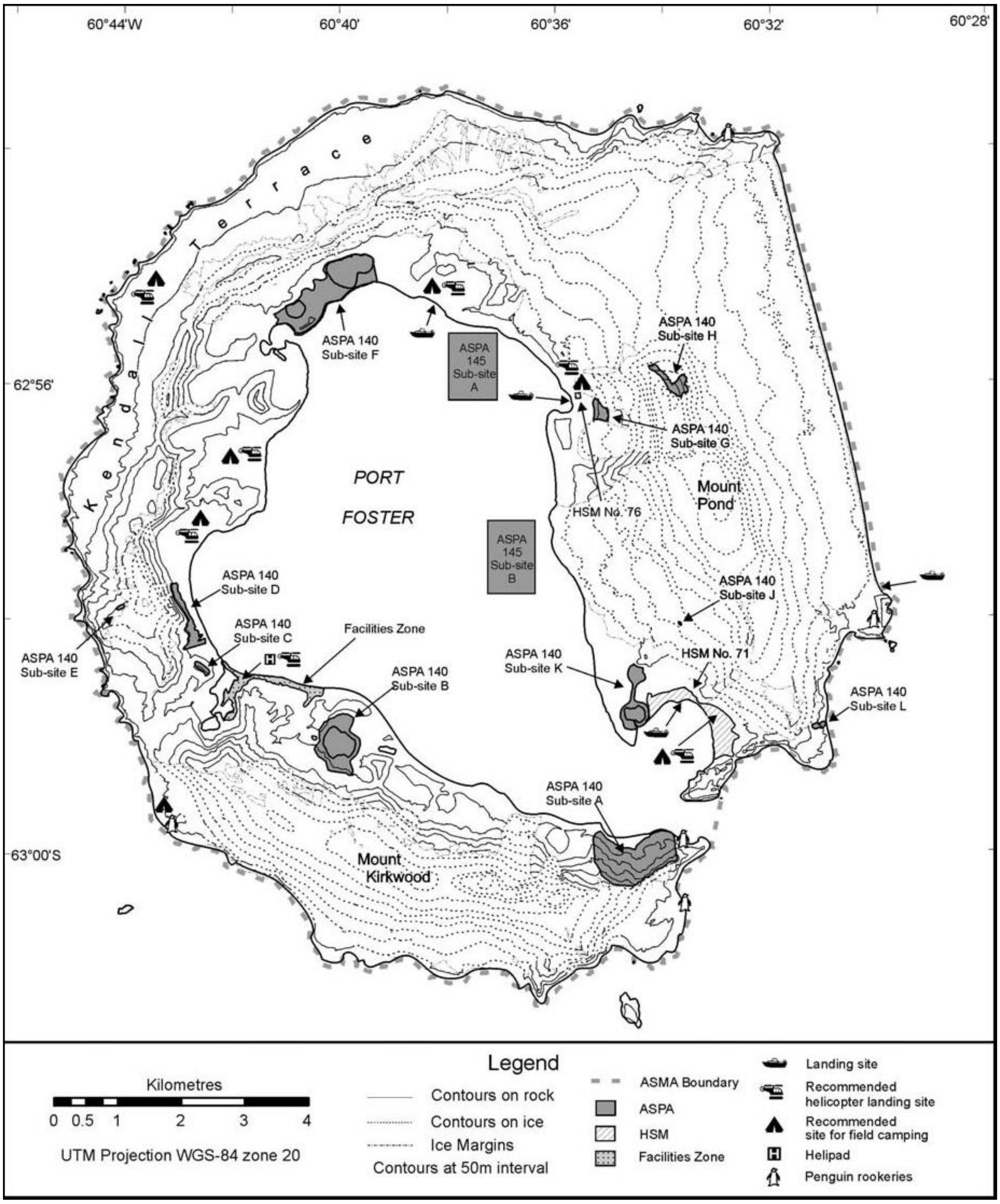

Fig. 8.1. Map of Deception Island. Source: British Antarctic Survey.

In the 1940's, as nations began to take interest in territorial claims in Antarctica, Argentina, Chile and UK respectively put in claims for Deception Island. UK founded Base B in Whalers Bay. Argentina established what is known today as Deception station. In 1955, Chile founded the station Pedro Aguirre Cerda and the refuge Gutierrez Vargas (Joyner and Ewing, 1991). Many buildings, including the Chilean and British stations and the abandoned whaling station were partially destroyed by volcanic eruptions in 1967 (Smellie 2001). Argentina's Deception and Spain's Gabriel de Castilla stations are the two active research stations on the island today.

Over the past five decades, nations including Argentina, Spain, UK, Brazil, Chile and USA have conducted scientific research in many areas of natural sciences, such as biological, oceanographic, geological and physical studies, operating out of land-based stations, field camps and vessels.

Since the end of the 20th century, Deception Island has become one of the most visited tourist destinations in the Antarctic. By mid 1990's, over 10,000 tourist landings[1] were made on Deception Island, at the four sites of Whalers Bay, Telefon Bay, Bailys Head and Pendulum Cove (Figure 8.2).

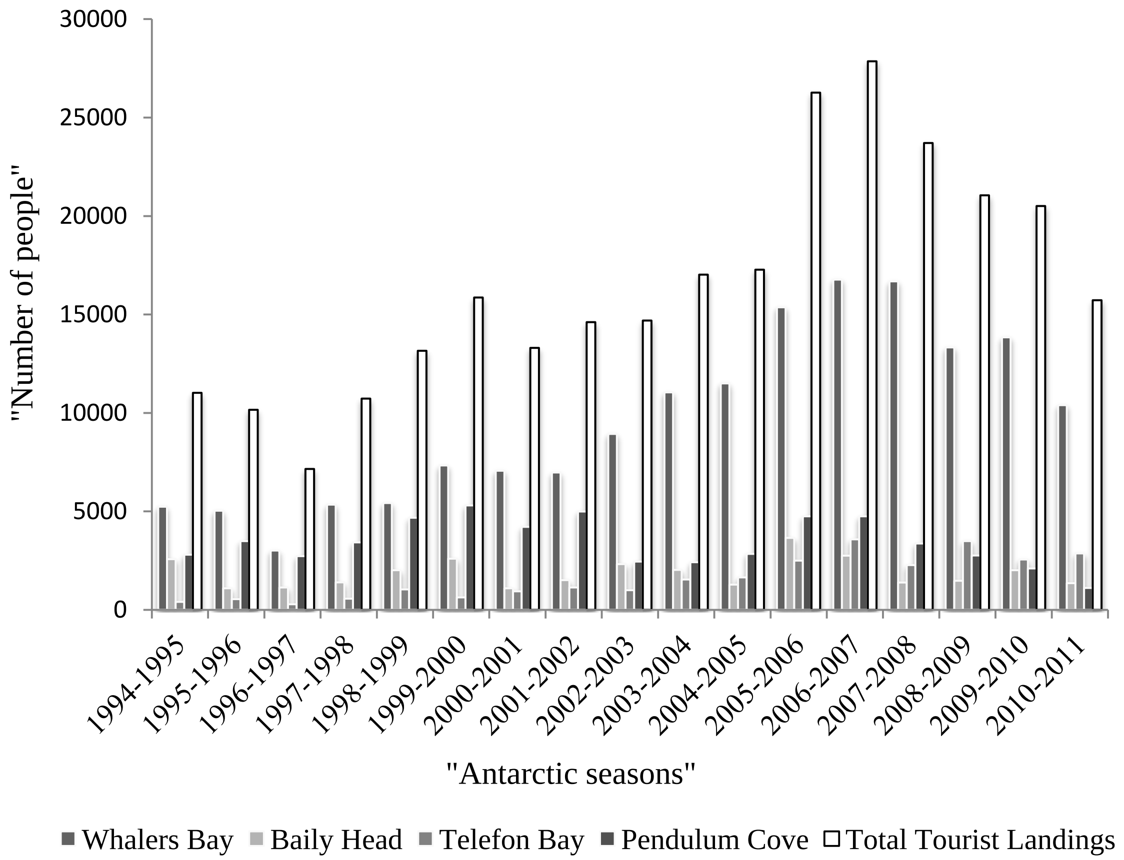

Fig. 8.2. Tourist landings on Deception Island (1994-2010). Data source: IAATO (2001a, 2001b, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011b)

[1] The International Association of Antarctica Operators (IAATO) publishes statistics on tourist visits to Antarctica under its member companies. IAATO has over 100 member companies that cover around 97% of the Antarctic tourism market. According to IAATO's statistics, a tourist landing is counted when a paying passenger gets off a ship and makes a visit at a land location. One passenger usually makes only one landing at each location but can make landings at several locations.

The sustained growth peaked in the 2007-08 seasons, with the record of over 25,000 tourist landings on Deception Island. Sailing yachts, carrying 1-12 passengers, are also commonly seen on Deception Island. Unlike larger cruise ships, the presence of sailing yachts is not regularly recorded and there is no clear information of non-IAATO cruises and private small yachts activities (Murray and Jabour 2004, Enzenbacher 2007). Casual observations suggest that the number of yachts visiting Deception Island is in the order of ten´s of yachts per year.

8.2.2 Regulatory mechanisms

Like the rest of the Antarctic Treaty Area, human activities on Deception Island are managed under the provisions laid out under (further discussed in Tin et al., this volume):

- The legal instruments of the Antarctic Treaty System, among them the Convention for the Conservation of Antarctic Seals (CCAS), Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) and the Protocol on Environmental Protection to the Antarctic Treaty (also known as the Environment Protocol);
- Other relevant international agreements, e.g., the International Convention for the Regulation of Whaling (ICRW) and the Agreement on the Conservation of Albatrosses and Petrels (ACAP); and
- Specific Measures, Decisions and Resolutions adopted at Antarctic Treaty Consultative Meetings (ATCMs).

Of specific relevance to Deception Island is the Deception Island Management Package adopted by the ATCM in 2005. This integrated management plan replaced piecemeal proposals for legal protection of different parts of the island with a coherent island-wide strategy to manage human activities (ATCM 2005). Deception Island was formally adopted as Antarctic Specially Managed Area (ASMA) 4 in 2005 under ATCM XXVIII Measure 3. It includes:

- Several Antarctic Specially Protected Areas (ASPAs), where entry is by permit only;
- Several Historic Sites and Monuments (HSM), where artefacts shall not be damaged, removed or destroyed;
- A facilities zone encompassing the two research stations, where human activities are subject to a code of conduct (Table 8.1);
- A series of general visitor guidelines and site-specific visitors’ guidelines (Table 8.2).

Table 8.1. Elements of the Deception Island Management Package. Antarctic Treaty Secretariat (2005).

Instruments	Management objectives	Selected management measures
MANAGEMENT PLANS FOR PROTECTED AREAS		
ASPA Nº 140 – Sites of unique botanical importance, Deception Island	Protecting and avoiding degradation to rare terrestrial flora while allowing scientific research to take place.	Entry by permit only, for compelling scientific reasons which cannot be served elsewhere or for essential management actions. Access to sites is by foot or small boat. Land vehicles, helicopter landings and camping are prohibited.
ASPA Nº 145 – Port Foster	Protecting and avoiding degradation to diverse marine benthic system while allowing scientific research to take place.	Entry by permit only.
CONSERVATION STRATEGIES FOR HISTORIC SITES & MONUMENTS		
HSM Nº 71 – Whalers Bay	Preserving the historic values of one of the most visited sites in Antarctica - remains of Norwegian Hector whaling station and British Base B.	No new buildings to be erected. Limited use of motorized vehicles. Recommended helicopter landing and camping locations. Site specific visitor guidelines.
HSM Nº 76 - Pedro Aguirre Cerda Station	Acknowledging the historic significance of Antarctic cultural and natural history.	Shall not be damaged, removed or destroyed.
CODES OF CONDUCT FOR DEVELOPMENT OF ACTIVITIES		
Code of Conduct for Facilities Zone, Deception and Gabriel de Castilla stations	Preserving natural, scientific and cultural values while encouraging scientific research in the area.	Consideration given to reusing existing sites when practicable, in order to minimize disturbance. Vehicles only used when necessary, on established tracks and away from flora or fauna areas.
Code of Conduct for Visitors	Preserving natural, scientific and cultural values while allowing education and tourism in the area.	<100 passengers ashore at any time. 1 guide for every 20 passengers. Do not walk on vegetation. Maintain 5-15 m from wildlife. Maintain at least 20 m from scientific equipment. Do not litter, graffiti or take souvenirs.

Table 8.2. Visitor Site Guidelines for the Deception Island landing sites. Antarctic Treaty Secretariat (2011).

Landing Site	Visitor Guidelines
Pendulum Cove	Safety requirements during use of bathing pits.
Whalers Bay	One ship <500 passengers at a time. Recommended landing, guided walking, and free roaming areas. Identification of closed areas. Bathing pits should not be dug. Hiking between Whalers Bay and Baily Head strongly discouraged.
Telefon Bay	One ship <500 passengers at a time. Recommended landing, guided walking and free roaming areas.
Baily Head	Maximum two ships each <200 passengers per day. <350 visitors ashore per day. No visitors between 22:00 p.m. and 4:00 a.m. Visits to colony should be in closely supervised groups of <20 visitors, well-spaced, one guide per group.

A management group, comprising of Argentina, Spain (both occupying research stations on Deception Island), Chile, Norway, UK (countries at the origin of the historic sites) and US (conducting field research regularly on the island), was established to coordinate, facilitate communication, maintain a record of activities and inspect and monitor for cumulative environmental impacts (ATCM 2006). The management plan has the advantage of short-term adaptability as it is revised every five years and can thus take into consideration new issues as they arise. In contrast the current management arrangements have difficulties in managing long-term issues, including systematic monitoring identifying cumulative impacts, and establishing higher standards of protection due to lack of agreement and conflicts of interest among stakeholders on these issues.

8.2.3 Values to be protected

Under the Deception Island Management Package, the island is protected for its “important natural, scientific, historic, educational, aesthetic and wilderness values” (ATCM, 2005). It is one of only two volcanoes in the Antarctic that has erupted in modern times. It contains a caldera with active geothermal processes and is likely to erupt again in the future. The area also has an exceptionally important flora, including very rare species of mosses associated with these geothermal areas and which have not been recorded elsewhere in the Antarctic (Smith 2005). There are numerous birds on the island with nine breeding species, according Bó and Copello (2001), including the world’s largest colony of chinstrap penguins *Pygoscelis antarctica* Forster 1781. The benthic habitat in Port Foster is also of ecological interest because of the perturbations caused by volcanic activity.

In terms of scientific values, Deception Island holds outstanding interest for studies in geoscience and biological science. It is a unique natural laboratory where the effects of natural and human perturbations can be studied directly. Historically, Deception Island has played a significant role in the history of human's involvement in Antarctica, acting as the stage for exploration, sealing, whaling and scientific research for two centuries. The aesthetic value of Deception Island is given by its unique landscape of a flooded caldera, linear glaciated coastline, barren volcanic slopes with fumaroles on steaming beaches, ash-layered glaciers, old and modern stations and a massive penguin rookery in the form of an amphitheatre at Baily Head (Downie 2007).

Deception Island´s natural and scientific values together with its rich historic and aesthetic values provide significant educational values on geophysics, marine and terrestrial biology and exploration heritage. Its volcanic landscape strongly contrasts with nearby locations. For all these reasons, Deception Island is one of the most visited tourism sites, and is part of the main tourist corridor to the Antarctic Peninsula (Lynch et al. 2010).

8.2.4 Known human impacts

Few of the effects of human activity on the environment of Deception Island have been examined in detail. The presence of infrastructure and footpaths is the most obvious evidence of human presence on Deception Island. Several footpaths have developed at tourism sites, such as Neptune's Window at Whalers Bay, and around heavily studied locations such as the chinstrap penguin rookery located in Vapour Col (Spain, 2010a). The impacts of foot traffic on Deception Island's soil fauna are being studied (Tejedo et al. in press; Tejedo et al., this volume). Rubbish has been found on beaches and along footpaths. Organic waste was found at Telefon Bay while plastic was the most common type of rubbish found at Pendulum Cove. Abandoned buildings at Whalers Bay are likely to be the source of wood, glass and metal waste materials found in nearby beaches (Spain, 2010a; Benayas, pers. observ.). Vandalism, including graffiti and damage of historical artefacts have taken place at historic sites (Roura et al. 2008). At Pendulum Cove, pools were dug in the sand to allow tourists to bathe in the geothermal water. The pools were rarely filled in after use, leaving obvious evidence of human presence. This practice has now largely been abandoned (Spain, 2010a).

8.3 LOOKING INTO THE FUTURE

8.3.1 Drivers of Change

8.3.1.1 Research and technology

Two research stations, several monitoring stations and two historic sites form the bulk of the long-term infrastructure found on Deception Island. Occupation of Deception station has remained below full capacity (65 people) in recent years, and has remained closed in some years. Gabriel de Castilla station has been operating at full capacity. Renovation works were completed in the 2009-10 season which extended the available living and research space inside the station to reach 36 people. Both research stations are expected to continue operating in coming years. It is unlikely that Deception station will need to be expanded in the near future due to the low occupation rates in recent years. Gabriel de Castilla station has seen a steady growth in occupation rates in the last twenty years (Fig. 8.3).

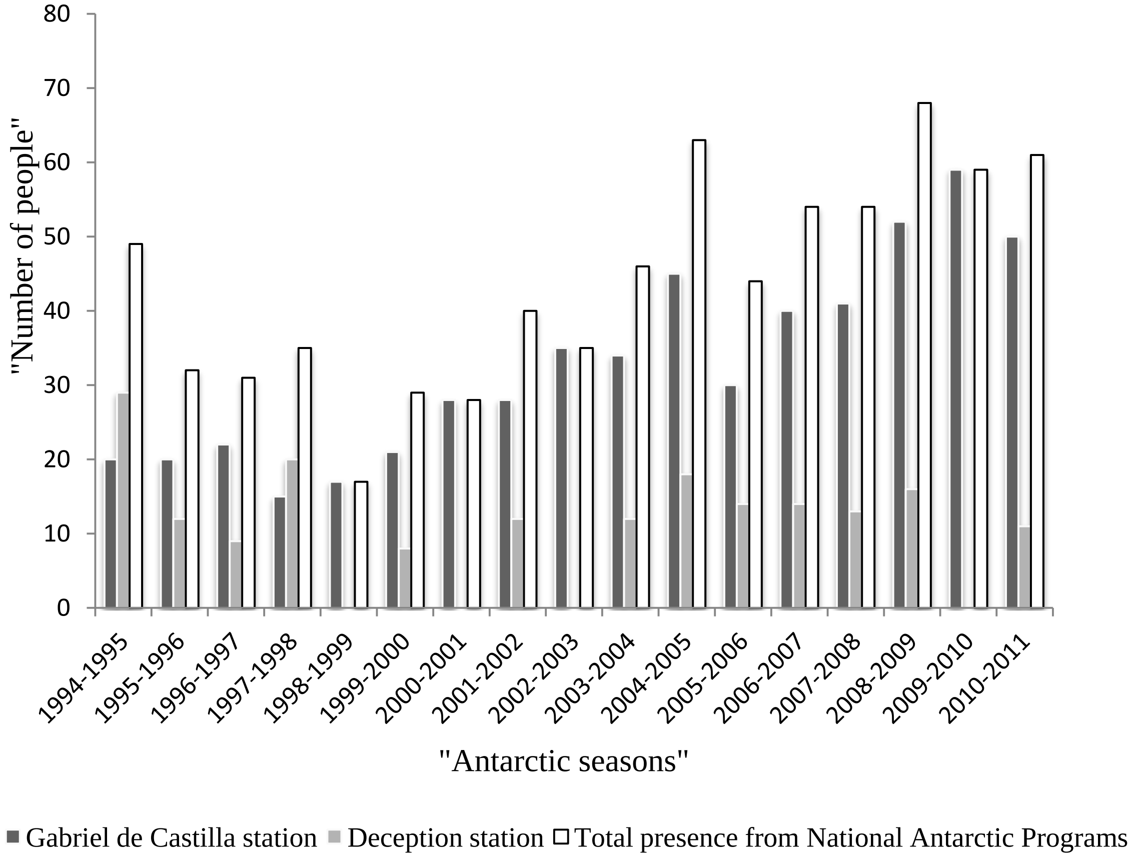

Fig. 8.2. Evolution of personnel at the two operating stations on Deception Island (1994-2011). Data for Gabriel de Castilla station obtained from Commander Francisco Lupiani (personal communications). Data for Deception station obtained from Commander Cristian Carrizo (personal communications).

Existing research projects focus on long-term volcanic and seismic monitoring, which are likely to continue operating. New technologies and research interests may attract more researchers to the station and/or use of field camps and establishment of instruments in more locations. Extrapolating from the trends of the last twenty years, we expect the capacity for Gabriel de Castilla station to increase to between 50 and 100 people in the next decades. Of course, there may be many kinds of constraints, e.g., economic, logistical, technological, that may limit this steady growth. New research technologies and interests may involve remote sensing techniques that require no visits to Deception Island (e.g., Fretwell et al. 2011, LaRue et al. 2011). Environmental monitoring and human impacts research may lead to management decisions that restrict certain human activities at certain locations or during certain times. Research activities can be affected by fluctuations in research budgets, and stations could be temporarily closed or expanded.

Continuous use of machines and infrastructure could potentially lead to leaks of heavy metals and hydrocarbons into the local environment. These parameters are currently not monitored regularly on Deception Island, and only a few ad hoc measurements are available (ASOC 2010, Cabrerizo et al. 2012). However, it is reasonable to expect that increases in human activity would increase the likelihood of local environmental pollution while decreases in activity would decrease the likelihood of pollution.

8.3.1.2 Tourism footprint

The number of tourists visiting Deception Island peaked in the 2006-07 season (Fig. 8.3). Since then, the number of tourists, cruise ships and voyages to Antarctica has decreased as a combination of global economic crisis, retirement of vessels and companies pulling out of the market (IAATO 2011a). Market demand to visit Antarctica is expected to continue, and therefore tourist numbers are expected to grow again from 2012 onwards should economic conditions become favourable (IAATO 2011b). Since August 2011, the International Maritime Organization (IMO) includes an amendment to the International Convention for the Prevention of Pollution From Ships (MARPOL) which bans heavy grade fuel oils in the Antarctic. This new regulation is not expected to decrease the number of cruise ships visiting Deception Island since most of the vessels entering Port Foster Bay are smaller, specialized vessels for polar waters that already operate with light fuel. With continued growth in market demand, as large cruise ships are removed from the market, the number of voyages based on small- and medium-sized vessels is likely to increase. This could, in turn, lead to a rise in the number of visits to popular sites, including Deception Island. We expect that the growth in tourism visits to Deception Island would resume as the global economic crisis ends. This growth may take different forms. Regional warming due to climate change may lengthen the tourist season (New Zealand 2009). In addition, improved centralized planning of ship routes and landings could maximize the number of possible landings per day at popular sites. Taking the example of Whalers Bay, coordinated planning could allow two ships to arrive and land a total of 400 passengers per day. Over a season of 120 days (Lynch et al. 2010), this would equate to a total maximum of 48,000 tourist landings per season, which is two to three times greater than current numbers. While, based on current trends, there is high likelihood that growth of tourism to Deception Island will continue, unexpected changes in social values and global economy could also temper our forecasts.

Increased human visitation could lead to increases in the formation of footpaths and potential impacts on soil fauna (Tejedo et al., this volume). Wildlife may be disturbed by visits by humans or noise from vessels and vehicles (de Villiers, 2008). The extent to which the seals on Deception Island are affected by human activity has not been examined. A study is currently underway to examine the stress levels of penguins on Deception Island associated with the cumulative effects arising from the continuous presence of human visitors (Pertierra unpubl. ms).

8.3.1.3 Marine traffic and accidents

Shipping traffic in the Antarctic Peninsula has increased significantly along certain routes (Lynch et al. 2010). At least two accidents have occurred in Deception Island in the last ten years. The *MS Lyuvov Orlova* ran aground in Whalers Bay in November 2006 and had to be assisted. In January 2007 The tourist ship *MS Nordkapp* struck underwater rocks at the entrance to Foster Bay, resulting in a minor damage to its outer hull and a small oil spill (Argentina et al., 2007). To our knowledge, both events have had minimal environmental impacts. Large oil spills would potentially lead to more severe environmental impacts. Normal ship anchoring and accidental running aground could potentially damage the unique benthic fauna in Port Foster (Spain, 2010a).

8.3.1.4 Introduction of non-native species

The Antarctic Peninsula is one of the areas of the world which is warming fastest (Turner et al. 2005, 2009; IPCC 2007). Climate change could increase the likelihood of the establishment of non-native species, whose seeds are carried to Antarctica by the increasing numbers of human visitors (Convey 2010). Due to its geothermalism and relatively high number of visitors, Deception Island is especially sensitive for colonization (Hughes & Convey, 2009). The non-native collembola *Hypogastrura viatica, Folsomia candida* and *Protaphorura sp.* have been found on Deception Island and their status of colonization still needs to be established (Greenslade 2010). Two non-native plant species, *Gamochaeta nivalis* Cabrera and *Nassauvia magellanica* JF Gmelin have been discovered recently at Whalers Bay in an area that was frequently visited. However, whether their origins were natural or human-mediated could not been ascertained (Smith & Richardson 2010). The introduction and spreading of non-native species could substantially impact local biology leading to, in some cases, the permanent loss of existing biodiversity and community structures (Hughes et al., this volume).

8.3.1.5 Volcanic activity

Active volcanism is an important driving force that has changed the landscape and human activity on the island. Eruptions in the late ‘60s early ‘70s devastated many buildings, including the Chilean and British stations which were not rebuilt. Scientific activity on the island was temporarily halted (Spain, 2010b). The volcano is still considered to be active and it is expected that further eruptions will take place. Seismic activity is monitored during the summer season and the Deception Island Management Package contains an escape strategy in case of an eruption. Future eruptions could severely affect existing human activities.

8.3.1.6 Other possible developments

Other developments may also take place in the future, even though they may be considered to be unlikely in view of current conditions, For example, it is possible that other nations not currently active on Deception Island would express their interest in establishing a new station on the island, although the number of suitable sites is limited. Temporary field camps could become permanents refuges or stations. Increased visits from yachts may be difficult to regulate. The construction of a runway on Deception Island could significantly increase the amount of human activity on the island (Dibbern, 2010).

8.3.2 Future regulatory scenarios

Bringing together the preceding sections on human activity, regulatory mechanisms, environmental impacts, values to be protected and drivers of change, we present four future scenarios for the management of Deception Island. The four scenarios represent different points along, firstly, one continuum that ranges from lower to higher level of environmental protection and, secondly, another continuum that ranges from lower to higher likelihood of stakeholder acceptance (Figure 8.4). Scenario A extrapolates from current trends into the future, assuming business will continue as usual. As new agreements will not be necessary, Scenario A has a higher likelihood to be accepted by stakeholders. The level of environmental protection delivered by Scenario A is expected to be lower than that of the other scenarios. Scenario B assumes that the island will be closed to all human access. While it delivers a higher level of environmental protection than Scenario A it also has a much lower likelihood of stakeholder acceptance. Scenario C proposes intermediate options that lie between the high acceptance / low protection Scenario A and the low acceptance / high protection Scenario B.

8.3.2.1 Future scenario (A): "Business as Usual"

The existing Deception Island Management Package provides a framework to coordinate science, logistic and tourism activities on the island. It has brought stakeholders together to agree on common environmental standards and has successfully promoted collaboration while avoiding direct confrontation. This way of working encourages consensus, commitment and support of regulations for the Deception Island ASMA, with implications on the wider Antarctic Treaty System. The management package aims to avoid '*unnecessary degradation and disturbance*' while implicitly accepting some impacts. Environmental impacts are mitigated (but not eliminated) while current legitimate activities are allowed to continue. Hence, under this scenario, necessary "degradation and disturbance" of the environment will continue even without any increase in human activity. With time, and with the expected increase of human activity, degradation, disturbance and impacts on the environment are likely to accumulate.

Research studies, such as quantifying the extent of human-facilitated transportation of non-native species, examining the accumulation and risk of marine pollution arising from shipping traffic, analyzing the effects of foot and vehicle traffic on Antarctic flora and soils and monitoring the levels of vandalism at historical sites, provide much needed scientific information on the environmental impacts of human activities on Deception Island. Many short-term studies have been conducted but a long-term, systematic and integrated monitoring system does not exist at the present. Baseline information on the current state of the island's ecosystems is sparse, with censuses and catalogues of species distribution often derived from national surveys. Site-specific guidelines stipulate the maximum number of visitors allowed, areas closed to visits, how visits to the colony should be conducted and the minimum distance that humans should keep with wildlife (ATS 2011). However, effectiveness of these guidelines cannot be evaluated since there is little scientific research or monitoring on the population of the colony, its trends or the effects of human visitation on it. There is also a lack of information on the actual level of compliance to management measures. Few cases of incompliance have been officially reported (e.g. Argentina et al. 2009), although anecdotal evidence raises concern on the increase of new graffiti on historic artefacts, occurrence of occasional unauthorised entry into closed areas, the need for higher guide to visitor ratios and the lack of monitoring and supervision of small independent yacht activities (Roura 2010, Benayas et al. unpubl. ms.).

As the current low level of integration between information and management continues under the Business-As-Usual scenario, human impacts on Deception Island are likely to become more than minor and transitory over the long term, permanently degrading the values that are currently being protected.

8.3.2.2 Future scenario (B): "No access"

In contrast to the Business-As-Usual scenario is a scenario which considers closing Deception Island to all human access, thereby avoiding further degradation of natural landscapes and values. This scenario could be created based on the necessity of giving priority to the protection of Antarctica's intrinsic, wilderness and aesthetic values as required under the Environmental Protocol - values that often receive less vocal support from human stakeholders. However, under current trends of human activities and engagement in the Antarctic, there is very low likelihood that this scenario will be adopted by consensus. The establishment of a reserve with no access could impede the ongoing research work which has great interest to the international scientific community.

8.3.2.3 Future scenario (C): "Intermediate protection"

In between the two extremes represented by Scenarios A and B lies a range of management options, which mixes various levels of environmental protection and likelihoods of being accepted and implemented. A first option, that we call *C1-Restricted Access*, includes the agreement among stakeholders to limit access during certain periods of time, or at certain locations. Closed areas and upper limits on number of people are strategies already in use (Tables X.1 and X.2) that could be extended and applied more widely. For example, maritime traffic into Port Foster could be limited to one ship per day, reducing the risk of accidents and limiting the magnitude and likelihood of environmental impacts. It could also be applied to sensitive sites such as breeding colonies or vegetated areas which have been impacted and are allowed to recover. Moreover, agreement could be reached among National Antarctic Programs to share their facilities and not to expand them any further, thereby reducing the human footprint, slowing down the process of accumulation of pollutants, and lowering the risk of introduction of non native species. However agreement on such measures would require stakeholders' participation and commitment and therefore may be potentially more difficult to achieve.

A second intermediate scenario, *C2-Higher standards*, focuses on reducing human impacts rather than human presence. It builds upon the framework of the existing Deception Island Management Package, introducing additional standards and protocols while allowing existing human activities to continue, thereby increasing the likelihood of stakeholder acceptance. The concept of Limited Acceptable Change (LAC) has been widely used in the management of National Parks in the USA (McCool and Cole 1998) and has been proposed as a management tool for Antarctic tourism (Davis 1999). Applying LAC to the case of Deception Island, stakeholders would agree on a system of indicators to be monitored and specific management actions to be implemented when trigger levels are reached. Current activities could continue to operate, but they will be delimited in order to minimize their environmental risks and keep their impacts to levels that are minor or transitory (New Zealand 2007). For example, soil compaction in a popular visitation site could be monitored and when compaction values reach a level that has been determined to significantly affect soil fauna, those areas will be temporarily closed (Tejedo et al. in press). New protocols can be introduced under this scenario and existing activities can be adapted to meet higher environmental standards. For example, biosecurity measures for Deception Island can be developed from the general measures recommended for the Antarctic Treaty Area (summarized in Hughes and Convey 2010) but also include additional measures designed specifically to address the challenges on Deception Island. Measures that are easy to implement are more likely to be accepted and applied.

The strength of the intermediate scenarios lies in the fact that they are more likely to be implemented by stakeholders than Scenario B, while at the same time providing higher levels of environmental protection than scenario A. However, their success relies on stakeholder involvement, systematic and continuous monitoring, scientific research and long-term commitment. Targeted research is paramount in filling in gaps on baseline information and improving understanding of key ecological relationships (Bargagli 2005, Kerry and Riddle 2009, Tin et al. 2009). A long-term integrated monitoring system can help to provide missing information, coordinate human activities, reduce duplication of research efforts and contribute towards sound science-based policy-making (Reid 2007).

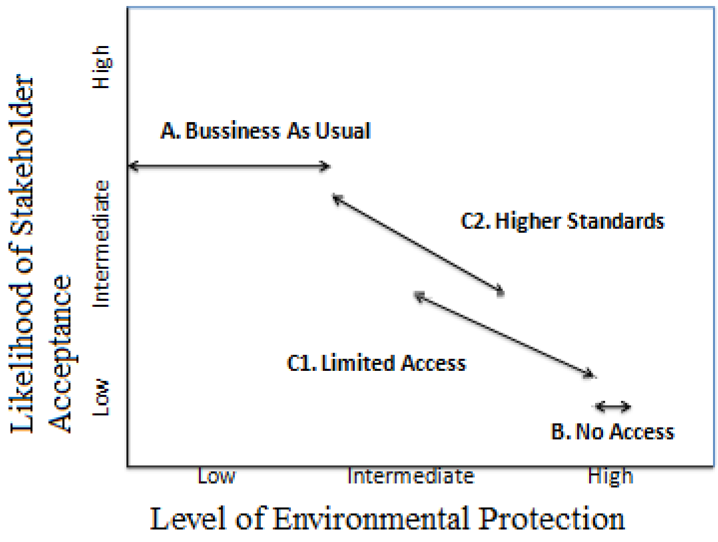

Fig. 8.4. Comparison of four future regulatory scenarios for Deception Island.

8.5 CONCLUSIONS

Deception Island is an emblematic site. It brings together protected areas, historic sites, scientific research and commercial tourism in one small space. Until now, self regulation of the tourist industry, complemented by Antarctic Treaty System guidelines and the recommendations from the Deception Island ASMA Management Group, has been sufficient to sustain conservation of the island (Haase et al. 2009). One possible weakness lies in the low level of environmental monitoring and lack of characterization of cumulative impacts for the long term. Long-term systematic environmental monitoring is a useful tool that can be developed to support decision making in the future.

The Deception Island Management Package has achieved a high level of acceptance from Antarctic Treaty parties in creating a zoning system to protect environmentally sensitive areas. It has succeeded in providing an elevated level of protection for the different values of Deception Island and it forms the basis from which future regulatory scenarios can be constructed. Looking into the future, we expect that the Deception Island Management Package would have difficulty in coping with the steadily increasing pressures from the growth of human activity and their cumulative impacts. An alternative scenario in which the island would be closed to all human access would result in no further degradation of the island's values and landscapes. This scenario represents the wilderness conservation position, being little represented in the parties involved on Deception Island and unlikely to achieve the levels of agreement needed for implementation and compliance. Between the extreme positions of these two scenarios, intermediate regulatory scenarios can be developed that can maximize the likelihood of stakeholder acceptance and level of environmental protection.

Intermediate scenarios can be based on a mixed formula that includes existing conservation strategies (such as the components in the Deception Island Management Package), additional standards of protection (including safety procedures) and limited access for vulnerable areas or critical periods. Such scenarios would allow current activities to continue while seeking commitment from all stakeholders to implement and comply to management measures and support the protection of Deception Island's values. In addition, the establishment of an early detection system would allow disturbances to the ecosystem to be detected and management measures to be implemented correspondingly. A systematic monitoring plan would be necessary in order to assess the efficiency of the policies in place and to anticipate future changes. Public awareness and involvement is a powerful tool that must be developed in the next years. In the case of tourism, guides have an important educational role whereas National Antarctic Programs have to put in place training courses to ensure that their personnel is familiar with the management measures that are in place. The extent to which these activities can be developed will depend on the interest of Antarctic Treaty parties in furthering the protection of Deception Island and the resources made available towards this goal.

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REFERENCES

ATS (Antarctic Treaty Secretariat) (2001) Antarctic Protected Areas System: Historic Sites and Monuments: Ruins of the Base Pedro Aguirre Cerda, Pendulum Cove, Deception Island, Antarctica. Measure 2, XXIV ATCM. St Petersburg, Russian Federation. 09 – 20 July 2001.

ATS (Antarctic Treaty Secretariat) (2005) Deception Island Management Package. Management Group. Measure 3, XXVIII ATCM. Bremen, Germany. 25-31 July 2004.

ATS (Antarctic Treaty Secretariat) (2011). Tourism and non-governmental activities. Site Guidelines for visitors http://www.ats.aq/e/ats_other_siteguidelines.htm

ASOC (Antarctic and Southern Ocean Coallition) (2010). Coastal Hydrocarbon Pollution. A Case Study from Deception Island, Antarctica. Information paper 81, XXXIII ATCM, Punta del Este, Uruguay. 3 - 14 May 2010.

Argentina, Chile, Norway, Spain, UK, USA (2006). Deception Island Antarctic Specially Managed Area (ASMA) Management Group. Information paper 19, XXIX ATCM, Edinburgh, UK. 12 - 23 June 2006.

Argentina, Chile, Norway, Spain, UK, USA (2007). Deception Island Antarctic Specially Managed Area (ASMA) Management Group Report. Information paper 108, XXXIV ATCM, New Delhi, India, 30 April – 11 May 2007.

Argentina, Chile, Norway, Spain, UK, USA (2009). Deception Island Antarctic Specially Managed Area (ASMA) Management Group Report. Information paper 131, XXXIV ATCM, Buenos Aires, Argentina. 20 - 30 June 2009.

Bargagli, R. (2005). *Antarctic ecosystems: environmental contamination, climate change, and human impact*. Berlin: Springer. 395 pp

Bastmeijer C.J. & Roura R. (2004). Regulating Antarctic Tourism and the Precautionary Principle. *American Journal of International Law*, Vol. 98(4): 763-781

Bauer, T. G. (2001). *Tourism in the Antarctic: opportunities, constraints and future prospects*. New York: The Haworth Hospitality Press. 275 pp

Bó, M.S. & Copello, S. (2001). Distribution and abundance of breeding birds at Deception Island, South Shetland Islands, Antarctica, February to April 2000, *Marine Ornithology*, 29(1), pp. 39-42.

Carpenter S.R., Mooney A.H., Agard J., Capistrano d., DeFriese r.S., Díaz S., Dietz T., Duraiappahh AK., Oteng-Yeboahi A., Pereira H.M, Perringsk C., Reid W.V., Sarukhan J., Scholesn RJ. & Whyteo A. (2009). *Proccedings for National Academy of Sciences*, 106 (5): 1305-1312.

Cabrerizo, A., Dachs, J., Varceló, D. & Jones, K.C. (2012). Influence of Organic Matter Content and Human activities on the Occurrence of Organic Pollutants in Antarctic Soils, Lichens, Grass and Mosses. *Environmental Science and Technology.*

Chile (1987) ASPA 145 Port Foster, Deception Island, South Shetland Islands. Recommendation 5, XXIV: Rio de Janeiro, Brazil, 05 – 17 October 1987.

Convey, P. (2010). Terrestrial biodiversity in Antarctica. Recent advances and future challenges. *Polar Sciences* 4:135-147

Davis, P. (1999). Beyond Guidelines. A model for Antarctic Tourism. *Annals of Tourism Research*, 26(3): 516-533

Dibbern S.J. 2010. Fur seals, whales and tourists: a commercial history of Deception Island, Antarctica. *Polar Record 46 (238): 210–221 (2010)*

De Villiers, M. 2008. Review of recent research into the effects of human disturbance on wildlife in the Antarctic and sub-Antarctic region. *In* SCAR *Human disturbance to wildlife in the broader Antarctic region: a review of findings*. Working paper 12. XXXI ATCM, Kyiv, Ukraine, 2-13 June 2008. Appendix 1.

Downling, R.K., 2003. Tourism in the Antarctic: opportunities, constraints, and future prospects. *Tourism Management*, 24(3), pp. 345-346.

Downie, R. (2007). Deception Island. In: Riffenburgh, B. (ed.) *Encyclopedia of the Antarctic.* New York, Routledge, 327-328.

Enzenbacher, D. (2007). Antarctic Tourism Policy-making: Current Challenges and Future Prospects. In: TRIGGS, G. & RIDDELL, A. (eds.). *Antarctica: legal and environmental challenges for the future*. London: The British Institute of International and Comparative Law. pp. 155-189.

Frenot Y., Chown S.L., Whinam J., Selkirk P.M., Convey P., Skotnicki M. & Bergstrom D.M. 2005. Biological invasions in the Antarctic: extent, impacts and implications. *Biological Reviews 80*, 45-72.

Fretwell, P., Convey, P., Fleming, A., Peat, H., Hughes, K. 2011. Detecting and mapping vegetation distribution on the Antarctic Peninsula from remote sensing data. Polar Biology 34(2): 273-281.

Greenslade, P. (2010). Collembola fauna of the South Shetland Islands revisited. *Antarctic Science*, 22(3): 233-242.

Joyner, C.C. & Ewing Jr., B. G. (1991) Antarctica and the Latin American States: The Interplay of Law, Geopolitics and Environmental Priorities, The Georgetown International Environmental Law Review, 4(1), pp. 1–46.

Haase, D., Lamers, M. & Amelung, B. (2009). Heading into uncharted territory? Exploring the institutional robustness of self-regulation in the Antarctic tourism sector. *Journal of Sustainable Tourism*, 17(4): 411-430.

Headland, R. (1994). Historical Development of Antarctic Tourism. *Annals of Tourism Research*, 21(2): 269-280

Hughes, K.A. (2010). How committed are we to monitoring human impacts in Antarctica? *Environmental Research Letters*, 5(4). DOI: 10.1088/1748-9326/5/4/041001.

Hughes, K.A. & CONVEY, P. (2010). The protection of Antarctic terrestrial ecosystems from inter and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. *Global Environmental Change*, 20: 96-112.

IAATO (International Association of Antarctic Tour-Operators) (2001a) Tourism Statistics. 1995-2000 statistics. Twelve Season Overview of Sites Visited in the Antarctic Peninsula - Part 1 (1989/90 - 1994/95). IAATO website: http://iaato.org/es/tourism-statistics. Last visited: 29/03/2012

IAATO (International Association of Antarctic Tour-Operators) (2001b) Tourism Statistics. 1995-2001 statistics. Twelve Season Overview of Sites Visited in the Antarctic

Peninsula - Part 2 (1995/96 - 2000/01). IAATO website: http://iaato.org/es/tourism-statistics. Last visited: 29/03/2012

IAATO (International Association of Antarctic Tour-Operators) (2002) Tourism Statistics. 2001-02 statistics. Number of visitors (tourists, staff, crew) per vessel – Peninsula Sites. Site Landings. IAATO website: http://iaato.org/es/tourism-statistics. Last visited: 29/03/2012

IAATO (International Association of Antarctic Tour-Operators) (2003) Tourism Statistics. 2002-03 statistics. Number of visitors (tourists, staff, crew) per vessel – Peninsula Sites. Site Landings. IAATO website: http://iaato.org/es/tourism-statistics. Last visited: 29/03/2012

IAATO (International Association of Antarctic Tour-Operators) (2004) Tourism Statistics. 2003-04 statistics. Number of visitors (tourists, staff, crew) per vessel – Peninsula Sites. Site Landings. IAATO website: http://iaato.org/es/tourism-statistics. Last visited: 29/03/2012

IAATO (International Association of Antarctic Tour-Operators) (2005) Tourism Statistics. 2004-05 statistics. Number of visitors (tourists, staff, crew) per vessel – Peninsula Sites. Site Landings. IAATO website: http://iaato.org/es/tourism-statistics. Last visited: 29/03/2012

IAATO (International Association of Antarctic Tour-Operators) (2006) Tourism Statistics. 2005-06 statistics. Number of visitors (tourists, staff, crew) per vessel – Peninsula Sites. Site Landings. IAATO website: http://iaato.org/es/tourism-statistics. Last visited: 29/03/2012

IAATO (International Association of Antarctic Tour-Operators) (2007) Tourism Statistics. 2006-07 statistics. Number of visitors (tourists, staff, crew) per vessel – Peninsula Sites. Site Landings. IAATO website: http://iaato.org/es/tourism-statistics. Last visited: 29/03/2012

IAATO (International Association of Antarctic Tour-Operators) (2008) Tourism Statistics. 2007-08 statistics. Number of visitors (tourists, staff, crew) per vessel – Peninsula Sites. Site Landings. IAATO website: http://iaato.org/es/tourism-statistics. Last visited: 29/03/2012

IAATO (International Association of Antarctic Tour-Operators) (2009) Tourism Statistics. 2008-09 statistics. Number of visitors (tourists, staff, crew) per vessel – Peninsula Sites. Site Landings. IAATO website: http://iaato.org/es/tourism-statistics. Last visited: 29/03/2012IAATO (International Association of Antarctic Tour-Operators) (2010) Tourism Statistics. 2009-10 statistics. Number of visitors (tourists, staff, crew) per vessel – Peninsula Sites. Site Landings. IAATO website: http://iaato.org/es/tourism-statistics. Last visited: 29/03/2012

IAATO (International Association of Antarctic Tour-Operators) (2011a). Report on IAATO Operator use of Antarctic Peninsula Landing Sites and ATCM Visitor Site Guidelines, 2009-10 & 2010-11 Seasons. Information Paper 105, XXXIV Antarctic Treaty Consultative Meeting, Buenos Aires, Argentina, 20 June – 1 July, 2011.

IAATO (International Association of Antarctic Tour-Operators) (2011b). Overview of Antarctic Tourism: 2010-11 Season and Preliminary Estimates for the 2011-12 Season. Information Paper 106, XXXIV Antarctic Treaty Consultative Meeting, Buenos Aires, Argentina, 20 June – 1 July, 2011.

IPCC (Intergovernmental Panel on Climate Change) (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Cambridge: University Press.

Kerry, K.R. & Riddle, M.J. (Eds.) 2009. Health of Antarctic Wildlife, A Challenge for Science and Policy. Springer: Heidelberg.

LaRue, M. Rotella, J., Garrott, R.,Siniff, D., Ainley, D., Stauffer, G., Porter, C., & Morin, P. 2011. Satellite imagery can be used to detect variation in abundance of Weddell seals (*Leptonychotes weddellii*) in Erebus Bay, Antarctica. Polar Biology 34(11): 1727-1737.

Lynch, H.J., Crosbie, K., Fagan, W.F. & Naveen, R., 2010. Spatial patterns of tour ship traffic in the Antarctic Peninsula region. *Antarctic Science*, 22(2), pp. 123-130

Martin, S. (1996). *A History of Antarctica*. State Library of New South Wales Press, Sydney

McCool, S.F. (1994). Planning for sustainable nature dependent tourism development: The Limits of Acceptable Change system. *Tourism Recreation Research*, 19 (2): 51-5.

McCool, S.F. & Cole, D.N. (1998) *Proceedings – Limits of Acceptable Change and Related Planning Processes: Progress and Future Directions*. Gen Tech. Rep. INT-GTR-371. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station

Mooney h.a., Cropper a. & Reid W. (2004) The Millennium Ecosystem Assessment: What is it all about? *TRENDS in Ecology and Evolution* Vol.19 (5): 221 – 224.

Murray, C. & Jabour, J., (2004) Independent expeditions and Antarctic tourism policy. *Polar Record*, 40(215), pp. 309-317

New Zealand (2007) Environmental Impact of Tourism and Other Non-Governmental Activities in the Antarctic Treaty Area. Working paper 13, XXX ATCM. New Delhi, India. 30 April – 11 May 2007.

New Zealand (2009). Past and future changes in sea ice around Antarctica. Working Paper 2, Antarctic Treaty Meeting of Experts on Ship-based tourism. Wellington, New Zealand, 9-11 December 2009.

Reid, K., 2007. Monitoring and management in the Antarctic making the link between science and policy. *Antarctic Science*, 19(2), pp. 267-270

Roura, R.M., Dos Santos, M., Perez, C.M. & Tin, T. (2008). *Tourism and the human footprint at Deception Island, South Shetland Islands, Antarctica*. SCAR/IASC IPY Open Science Conference. Polar Research: Arctic and Antarctic Perspectives in the International Polar Year. St.Petersburg, Russia, July 8 - 11, 2008

Roura, R.M. (2010). *Being there: Tourist behaviour, impacts, and compliance as assessed through Antarctic tourism Web logs*. Oslo Science Conference 2010. Oslo, 8-12 June 2010

Roura, R. & Hemmings, A.D. (2011) Realising Strategic Environmental Assessment In Antarctica. Journal of Environmental Assessment Policy and Management 13(3): 483-514.

Spain (2010a). Deception Island Antarctic Specially Managed Area (ASMA) Management Group. Information paper 20, 33rd Antarctic Treaty Consultative Meeting, Punta del Este, Uruguay. 03 - 14 May, 2006.

Spain (2010b). Deception Island Antarctic Specially Managed Area (ASMA) Management Group. Information paper 19, 33rd Antarctic Treaty Consultative Meeting, Punta del Este, Uruguay. 03 - 14 May, 2006.

SMELLIE (2001) Lithostratigraphy and volcanic evolution of Deception Island, South Shetland Islands. *Antarctic Science 73 (2): 788-209*

Smith, R.I.L.(1988) Botanical survey of Deception Island. British Antarctic Survey Bulletin 80: 129-136.

Smith, R.I.L. (2005) The thermophilic bryoflora of Deception Island: unique plant communities as a criterion for designating an Antarctic Specially Protected Area*Antarctic Science 17 (1): 17–27*

Smith, R.I.L. & Richardson, M., (2011) Fuegian plants in Antarctica: natural or anthropogenically assisted immigrants? *Biological Invasions,* 13(1), pp. 1-5.

Tejedo, P., Pertierra, L., Benayas, J., Convey, P., Justel, A. & Quesada, A. (in press). Trampling on Maritime Antarctica. Can soil ecosystems be effectively protected through existing codes of conduct? *Polar Research.*

Thomas, D.N., Fogg, G.E., Convey, P., Fritsen, C.H., Gili, J.M, Gradinger, R., Laybournparry, J., Reid, K. & Walton, D.W.H. (2008). *The Biology of Polar Regions (2nd Edition)*. Biology of Habitats Series. Oxford University Press. 416 pp.

Tin, T., Fleming, Z.L., Hughes, K.A., Ainley, D.G., Convey, P., Moreno, C.A., Pfeiffer, S., Scott, J. & Snape, I., (2009) Impacts of local human activities on the Antarctic environment. *Antarctic Science,* 21(1), pp. 3-33.

Turner, J., Bindschadler, R. A., Convey, P., Di Prisco, G., Fahrbach, E., Gutt, J., Hodgson, D. A., Mayewski, P. A. & Summerhayes, C. P. (Eds.) (2009). Antarctic Climate Change and the Environment. Cambridge: Scientific Committee on Antarctic Research.

Turner, J, Colwell, S.R. Marshall, G.J. Lachlan-Cope, T.A. Carleton, A.M. Jones, P.D. Lagun, V. Reid P.A. & Iagovkina S. (2005) Antarctic climate change during the last 50 years. Int. J. Climatol. 25: 279–294 (2005)

United Kingdom (1985) ASPA 140 Parts of Deception, Deception Island, South Shetland Islands. Recommendation 8. XIII ATCM, Brusselas, Belgium 08 – 18 October 1985.

Vaughan D.G., Marshall, G.L, Connolley W.L, Parkinson C, Mulvaney R, Hodgson D.A., King J.C, Pudsey C.J. & Turner J. (2003). Recent rapid regional climate warming on the Antarctic Peninsula. *Climatic Change* 60: 243–274.

Capítulo

5 Discusión

DISCUSIÓN

En los pasados capítulos se han detectado una serie de problemas ambientales locales o específicos, asociados a la presencia humana local o a una actividad particular en la Antártida. Estos resultados en conjunto dan lugar a valoraciones globales y destapan cuestiones adicionales sobre los retos de conservación futura en la Antártida. Al respecto el presente capítulo narra las distintas reflexiones surgidas en la investigación sobre estas cuestiones.

5.1 EL IMPACTO HUMANO ACUMULADO EN LA ANTÁRTIDA

La presencia humana en la Antártida genera un legado histórico, cada vez más extenso y menos valioso, con crecientes impactos (Tin et al. 2009). Los primeros exploradores dejaron restos de su actividad e infraestructuras en forma de refugios y rutas, ahora convertidos en monumentos o sitios históricos (H.S.M.). Los foqueros dejaron refugios, hoy reconocibles como sitios arqueológicos, como legado de su actividad (Smith & Simpson 1987). Los balleneros dejaron tras su paso factorías, como la de Bahía Balleneros en Isla Decepción (H.S.M. 71), un sitio histórico de visita frecuente a la vez que un ejemplo iconográfico de la huella de actividades extractivas pasadas. Las primeras bases obsoletas han quedado igualmente como ejemplo de las primeras actividades soberanistas y científicas (HSM 76). Con este panorama cabe esperar una huella proporcional de las actividades presentes que dejará un legado de bases, senderos en sitios turísticos, campamentos o estaciones remotas de medida salvo aquellas que específicamente son diseñadas pensando en su eliminación futura y son eventualmente retiradas. La huella de tales actividades, reiteradas y diversificadas año tras año, se va incrementando (Braun et al. 2012). Es tal la magnitud de actividades que el propio suelo antártico virgen es considerado un recurso en agotamiento (Hughes et al. 2011). Con este panorama el continente se encuentra en cambio, un cambio gradual, en el que mientras unos valores de conservación se deterioran (valores naturales y científicos) otros crecen y se diversifican (valores educativos e históricos). Si bien, puede discutirse que las infraestructuras generadas en las pasadas décadas carecen de valor histórico, y que los valores educativos son en realidad únicamente recreativos (Roura 2012). Por otro lado los valores paisajísticos dependen de la percepción de los sujetos, mientras los cambios y la humanización constituyen un símbolo de progreso para unas personas, otros lo consideran una pérdida del patrimonio natural (Summerson et al. 2012). Los trabajos de Ensminger et al. (1999) muestran la necesidad de proteger valores paisajísticos e intrínsecos frente a otros valores, así como la relevancia de definir con precisión y evaluar los impactos acumulativos. Asimismo la perturbación de los hábitats y las comunidades biológicas naturales transforma los ecosistemas. En los pasados capítulos se estudian algunos de estos impactos, a los que se suman otras amenazas mundiales como la contaminación oceánica y el cambio climático que inciden sobre los ecosistemas polares (Clarke & Harris 2003, Smetacek & Nicol 2005, Nash 2011). Estos agentes de cambio globales y otros aspectos menos tratados como los cambios en la biodiversidad microbiana inciden inicialmente de manera poco visible pero inexorable en los sistemas antárticos, recibiendo cada vez mayor importancia (Sutherland et al. 2012). La suma de estas alteraciones provoca sucesivamente cambios cada vez más profundos en lo que entendemos como el ambiente antártico. Ante una transformación progresiva, extendida en el tiempo y manifestada gradualmente, solamente podemos afrontarla de la misma forma, pensando de antemano y actuando en conjunto, esto es integrando las distintas perspectivas en una estrategia global de gestión ambiental (Tin et al. 2012).

5.1.1 La huella a largo plazo por pisoteo del ser humano

La huella humana por pisoteo es el primero de los impactos en el medio y uno de los más evidentes. En sitios de visita la masificación reiterada puede suponer un problema. Tal como se vio en el capítulo 4.1 la resistencia de las comunidades vegetales criptógamas se ve limitada a unos pocos de centenares de visitantes antes de ser completamente denudadas por el pisoteo. Las praderas de musgos son un elemento frecuente en las zonas libres de hielo de las islas Shetland del Sur y la Península Antártica, pero en pocos casos alcanzan una gran extensión. Las visitas turísticas a estas zonas, y el establecimiento de campamentos o bases amenazan estas singulares praderas. Desde hace décadas se han detectado estos daños en lugares como la Península Fildes (Olech 1996) debido a la aglomeración de bases y el tráfico de vehículos terrestres (Braun et al. 2012). A su vez, la expansión de la hierba introducida *Poa annua* se ha visto facilitada por la dispersión humana por pisoteo y tráfico de vehículos colonizando nuevos ambientes y extendiéndose de forma irreversible por la península (Molina-Montenegro et al. 2012).

- Carga de visitantes en sitios de visita. El transito anual de miles de visitantes en la Isla Barrientos, la pradera de mayor extensión de *Sanionia georgico-uncinata* conocida en la Antártida Ochyra et al 2007, está generando visibles procesos de denudación de la vegetación. Las visitas se encuentran encauzadas por senderos, limitando en gran medida el impacto (Tejedo et al. 2012). Hay dos recorridos alternativos, uno por zonas altas mas áridas (sendero central de la isla) de uso tradicional, y otro por zonas costeras con arroyos y vegetación (sendero costero) con un uso más reciente. Parte de los senderos discurren por zonas con alto grado de encharcamiento dando lugar rápidamente a tramos embarrados en el trazado original. Las comunidades criptógamas han visto reducida su extensión sin que se conozca realmente una cifra aproximada de la extensión denudada. Estas comunidades se caracterizan por un bajo grado de resistencia, ya que contienen gran cantidad de agua y biomasa (equivalentes a las comunidades A del capítulo 4.1). En estas zonas el trazado del sendero se pierde debido al deseo de evitar las zonas embarradas conformando una red de trazados que se va incrementando según las nuevas zonas empleadas se convierten en nuevas masas de barro. Se observa claramente como el principio de evitar biotopos sensibles se está incumpliendo en este sendero costero. Ante la gravedad de la situación se han puesto en marcha diferentes mecanismo de gestión a través de las reuniones anuales del Tratado. Próximo a este enclave se encuentra la cercana base ecuatoriana Maldonado cuyos investigadores han asumido un seguimiento de la actividad turística de Isla Barrientos. Así, nuestro grupo de investigación de la UAM ha iniciado una estrecha colaboración con el equipo de Ecuador. Tras detectar el agravamiento de este proceso en los últimos años se optó por presentar en 2012 a la reunión consultiva de Hobart en 2012 el documento de trabajo Nº 56 (Ecuador y España 2012) en la que se buscaba tomar una decisión al respecto. La medida adoptada fue preventiva, desaconsejando el tránsito por ambos senderos, limitando las visitas en los extremos oriental y occidental de la isla. Para más información consultar la Resolución 5 (ATCM XXXV 2012b). Ante estas provisiones cabe preguntarse el efecto de estas medidas. Según los trabajos que venimos realizando en la Península Byers (datos sin publicar) las zonas encharcadas del sendero costero podrían recuperarse relativamente rápido frente a las praderas más secas definidas en el capítulo 4.1. Por ello es esperable una recuperación parcial en un breve lapso tras la clausura del sendero en estos tramos (trabajos en desarrollo). No obstante nuevos usos reproducirían nuevamente el problema. En el caso del sendero central la denudación es fruto de un intenso pisoteo durante décadas en una zona más árida (que se asemeja a la comunidad B). Según nuestras estimaciones la recuperación de este sendero sería mucho más lenta. Ha de valorarse igualmente la capacidad de las comunidades de la isla para acoger visitantes, definir la carga máxima que puede soportar y los Limites de Cambio Aceptable LAC que se permitan. Al respecto en base a los estudios del capítulo 4.1 el límite observado experimentalmente de las comunidades es de muy pocas personas en las zonas de musgos encharcados y de pocos centenares en el sendero central, muy por debajo de las cifras actuales (miles de visitantes). Por ello pensamos que la formula apropiada consistiría en cerrar de forma permanente el sendero costero y usar como zona de sacrificio el sendero central como se viene haciendo la última década pero con una limitación de carga. No obstante, el seguimiento en futuras campañas de la recuperación en el sendero central es clave para la efectividad de esta medida. No se deben olvidar igualmente otros aspectos en la configuración final de la red ya que esta evaluación se ha realizado de acuerdo a la amenaza inminente sobre la vegetación. Se desconoce el impacto que supone el uso de uno u otro sendero sobre otras comunidades terrestres. Por ejemplo en la fauna marina, en particular sobre las vulnerables colonias de petreles, así como de elefantes y lobos marinos. También deben valorarse las posibles perturbaciones a las colonias presentes de pingüinos papúa y barbijo (en este caso véase 5.1.3). Igualmente señalar las alteraciones sobre las poblaciones de fauna edáfica, en particular los efectos sobre la biodiversidad genética de colémbolos están siendo estudiados (Tejedo et al. en prep.) Finalmente, la exclusión de la isla Barrientos como sitio de visita turística es una alternativa que ha de ser valorada igualmente tras evaluar los daños globales a los valores naturales del enclave.

- Minimizando los daños en áreas protegidas: Otros espacios como la Península Byers se han librado de estos daños masivos gracias a su grado de protección. La península Byers es potencialmente más vulnerable debido a su gran extensión y el alto grado de concentración de la vegetación en las playas del Sur, conformando una gran explanada propicia para la instalación de bases. La ocupación queda reducida a campamentos con un número reducido de investigadores lo cual a priori-limita el impacto. No obstante, si consideramos que los turistas contrariamente a los investigadores llevan a cabo una única visita y con un recorrido circular o de ida y vuelta por un sendero, su presión equivalente a grosso modo responde a: *Nº de visitantes x Nº de pasadas (1 ó,2)*. La presión seria de una vez o dos el número de visitantes totales, tomando como ejemplo Barrientos serian 7200 o 14400 pasos anuales por sendero. En el caso de los científicos dependería del tiempo de estancia (desde una visita corta un día, a un mes o una temporada) y la frecuencia de uso diario de la ruta (Ninguna, Una, Varias): *Nºcientíficos x Estancia promedio (1,30,90) x Nº de pasadas diarias (0,1,8).* La presión real puede ser muchas veces el número total de científicos. Siguiendo con el ejemplo de Byers, una cifra de 10 investigadores anuales con una estancia media de 1 mes y 2 paso diarios corresponde a una presión de 600 personas por temporada en lugares de interés, que podría superar 1600 en rutas muy frecuentes (tal como observamos en el capítulo 4.5). La carga sigue siendo menor pero como vimos en el capítulo 4.1 en rutas de uso diario es suficiente para generar efectos muy graves en la vegetación. Además aparecen comunidades más vulnerables y se encuentran condicionadas por factores agravantes como el grado de encharcamiento, el tipo de suelo o la biomasa acumulada. Así localmente unos pocos investigadores pueden generar un impacto considerable si no se llevan a cabo estrategias de minimización de los daños tales como definir senderos como zonas de sacrificio para los enclaves de interés y evitar biotopos sensibles. En el caso del campamento español en Península Byers (ASPA 126) estas medidas han sido implementadas con éxito durante su ciclo de vida como tal sin observarse un impacto visual en las extensas praderas de musgos (evitadas). Debe señalarse que el sendero a la playa (de uso muy frecuente) discurre por un arroyo (similar al sendero costero de Barrientos). Este sendero atraviesa puntualmente alfombras de musgos en los que se observa testimonialmente la denudación lo que nos indica los graves efectos que se producirían en la pradera si este sendero discurriese a unos pocos metros de su ubicación.

Es importante concluir que si bien las rutas alternativas eliminan un impacto sobre la vegetación estas inevitablemente tienen su coste sobre otras comunidades terrestres. Tejedo et al. (2009) mostraron los impactos sobre la fauna edáfica y las propiedades del suelo en zonas libres de vegetación. Un daño que debe ser asumido y que debe entenderse como mínimo y transitorio a pequeña escala. Tejedo et al. (2012) estimaron una recuperación aparente de estos senderos a los 2 o 3 años. Esto nos hace pensar que es preferible caminar por estos ambientes ya que desconocemos las capacidades de recuperación de la vegetación de crecimiento (potencialmente) potencialmente lento en estos ambientes. Es necesario en el futuro conocer la resiliencia de las comunidades vegetales para realizar evaluaciones globales de la vulnerabilidad relativa de todas las comunidades terrestres. En el caso del tránsito por arroyos los efectos del pisoteo sobre las comunidades acuáticas están poco o nada estudiados en estos ambientes, lo que llama a la precaución ante el uso de estos como redes de paso. Puede pensarse que el alto grado de dinamismo que sufren estas aguas con los ciclos de hielo y deshielo y el arrastre de materiales nos sugiere una mayor resistencia a las perturbaciones de las comunidades que vivan en ellos. No obstante, es necesario evaluar en profundidad los impactos antes de extender su uso como zona de paso (especialmente en sitios de gran transito). La estrategia aplicable para minimizar el impacto por pisoteo en ambientes terrestres debe incluir en primer lugar evitar el paso sobre las comunidades vulnerables. Las áreas protegidas como Byers son lugares emblemáticos en los que se exige el máximo nivel de conservación, así el impacto debe ser mínimo. En caso de ser inevitable el paso, debe considerarse delimitar senderos marcados para acotar la extensión afectada (en el caso de rutas frecuentadas). En los lugares con mayor presencia humana es especialmente necesario restringir estos efectos ya que el impacto es acumulativo.

5.1.2 La introducción continua de especies y la pérdida de biodiversidad

Se ha observado que las especies introducidas en la Antártida compiten con las especies nativas por el hábitat disponible y modifican las condiciones del ecosistema natural. La llegada de personas al continente antártico ha traído consigo de forma accidental o deliberada numerosos propágulos de especies no nativas. A su vez las barreras naturales que frenan su asentamiento se encuentran debilitadas por el cambio global iniciado por el ser humano (Lee & Chown 2009). De entre todos los propágulos que alcanzan los ecosistemas antárticos, sólo las especies más exitosas (aquellas que superan las barreras naturales del continente extremo) consiguen establecerse y extenderse.

- Superviviente de largo periodo. La tasa de llegada de agentes invasores ha cambiado en el tiempo según se ha incrementado la noción sobre su problemática. Los primeros organismos introducidos en islas sub-antárticas. son hoy un grave problema. En la Antártida algunas de las plantas traídas en experimentos de germinación han persistido y con el cambio climático y la movilidad de los PNA las más resistentes se han ido expandiendo. Aunque hoy en día esta amenaza ha sido limitada existen numerosos casos de introducciones previas a esta regulación, de los cuales el género Poa ha sido el más exitoso entre las plantas vasculares. Este género fue introducido en el siglo XX en varios sitios diferentes de la Península antártica, la especie *Poa annua* ha conseguido establecerse progresivamente en distintos lugares (Molina-Montenegro et al. 2012). Mientras tanto la especie *Poa pratensis* es otra planta que persiste desde su introducción, ya en 1955, en experimentos de germinación en la Caleta Cierva, siendo la planta no nativa más longeva, pero contrariamente a la *Poa annua* no se ha observado ningún proceso de expansión, si bien la última inspección documentada es de 1995. De esta manera en la campaña 2011-12 se inspeccionó el lugar de introducción de la *Poa pratensis* a fin de realizar un seguimiento a la planta. Se tomaron muestras de los individuos encontrados y las especies acompañantes, que posteriormente fueron examinados en laboratorio. Igualmente, para situar las condiciones ambientales, se analizó el registro de temperaturas de los meses de verano en la región observando las dificultades de la planta para florecer y dispersarse, a la vez que el creciente éxito en el crecimiento vegetativo de la especie no nativa. Aunque la introducción deliberada de especies no nativas está altamente regulada hoy en día, el riesgo de introducción accidental crece con la presencia humana actual. Impactos como el pisoteo y la denudación de la vegetación natural proporcionan unas condiciones favorables para el establecimiento de agentes invasores en aquellas zonas de mayor tránsito humano. Asimismo el marco de cambio climático proporciona progresivamente ambientes más propicios para la persistencia de las especies introducidas. Como resultado de esta investigación hemos observado como las barreras naturales y antrópicas que frenan la entrada de agentes colonizadores se están debilitando.

Por otro lado cabe plantearse las estrategias de contención. La Poa annua representa hoy un problema de muy difícil erradicación. En cambio con la Poa pratensis relegada a la Caleta Cierva es posible aun hoy una actuación efectiva para evitar su expansión. Pese a su largo periodo de permanencia son destacable los escasos trabajos dedicados a ella. Apenas hay constancia de su andadura durante más de 6 décadas. En la campaña 2011-12 tuvimos la oportunidad de trabajar en Caleta Cierva y constatar su persistencia. Así, la primera medida de gestión fue informar sobre el estado actualizado de la planta a través del Documento informativo Nº 13, (Reino Unido y España, 2012). Tras documentar su permanencia la siguiente acción debía ser evaluar su estado y el riesgo presente y futuro que suponía su desarrollo. El buen estado de las plantas y el crecimiento lateral indican su grado de aclimatación. No obstante la ausencia de efectiva formación de semillas nos indica que su dispersión es aún poco viable. Ante una amenaza futura similar a la Poa annua parece altamente fundamentada la erradicación preventiva de una planta introducida por una acción humana documentada.

- Nuevas vías de entrada En la actualidad la introducción deliberada de organismos no nativos está muy controlada. Experimentos como los de mediados de siglo XX han quedado del todo prohibidos tras la aplicación del Protocolo de Madrid (1991). Sin embargo, existen otros vectores de introducción. Hoy día la vía de entrada principal de organismos alóctonos a la Antártida es de manera no intencionada en forma de propágulos. Se han desarrollado protocolos para evitar la carga de propágalos que llegan a la Antártida, y aunque estas medidas limitan los riesgos, no acabar completamente con ellos. Las vías de entrada más destacadas son ropa de los visitantes (turistas y científicos), los materiales personales y el cargamento de soporte a las bases científicas e instalaciones permitidas (Hughes et al. 2006). Por otro lado han de incluirse los propágulos marinos traídos con los barcos en el casco o el agua de lastrado (hoy regulada por la IMO). Los propágulos vegetales suponen una entrada más exigente que la introducción de individuos adultos, ya que deben soportar las condiciones extremas del medio para germinar, desarrollarse, persistir y reproducirse. Como vimos en el capítulo 4.2 parecen ser las fase más vulnerables las de la reproducción y germinación. Aun así, hay organismos que superan todas estas barreras y amenazan las comunidades locales. Además el calentamiento regional va creando cada vez condiciones más favorables para esta vía de entrada.

Actualmente la entrada de especies invasoras en la Antártida es un proceso casi irremediable con la gran presencia humana del momento. Braun et al. 2012 señala la como lugar de especial riesgo la Península Fildes. En este espacio la intensa actividad humana ha facilitado ya la entrada de al menos dos especies no nativas en las ultimas décadas, la extendida Poa annua (Olech et al. 1996, Molina-Montenegro et al. 2012), y muy recientemente *Juncus bufonios* (Cuba-Diaz et al. 2012).Los protocolos de actuación ponen freno a gran número de bioinvasiones pero no resuelven el problema.

- Invasiones a otros niveles Por otro lado frente a las bioinvasiones que son fácilmente detectadas están las que apenas reconocemos, como son las de muchos microorganismos (Cowan et al. 2012). Aparecen dos vertientes opuestas en cuanto a la biogeografía de los microorganismos que son necesarias de señalar ya que en una de ellas los microorganismos son ubicuos y por tanto no hay invasiones como tales. Por otro lado es posible que si hayan comunidades nativas. En este caso hay dos nuevas posibilidades para la interacción: que la comunidad bacteriana constantemente repela los agentes externos de forma natural por competencia; o bien es posible que haya una llegada de agentes invasores y que desplace la comunidad local. Es evidente que una planta superior establecida modifica el ecosistema, pero ¿hasta qué punto introducciones en la comunidad bacteriana cambian la funcionalidad del sistema? No existe hoy consenso científico en todas estas cuestiones. Poniéndonos en el supuesto de que ocurriera de la ultima forma podemos pensar que hoy en día con los medios que disponemos estamos contaminando continuamente el sistema. Y que para evitar la carga de invasiones la única posibilidad es la total ausencia humana en determinados ambientes a fin de protegerlos como tales. Por otro lado en los ambientes más ocupados (tales como las costas de las Islas South Shetland) definir el grado de perturbación del sistema natural originario y limitar su degradación. Aun así incluso en estos lugares es posible proteger espacios más remotos en los que la presencia humana haya sido muy limitada o nula. A modo de ejemplo, citar el Promontorio Ray en la Península Byers. Esta zona ha recibido un número muy moderado de visitas desde su protección en 1956 debido a su difícil acceso. Este espacio ha sido designado como lugar santuario dentro del ASPA. Su acceso está muy limitado y precisa de una justificación excepcional, más allá del permiso de entrada al ASPA, precisamente para preservar estas comunidades microbiológicas nativas. En caso de concederse dicho permiso, el acceso debe realizarse con trajes estériles que eviten la contaminación del entorno (véase ASPA 126 Management Plan).

A modo de conclusión, la declaración de lugares santuario parece una fórmula interesante para preservar intactas las comunidades microbiológicas. Sin embargo todavía presenta cuestiones por resolver. Por un lado, la cercanía de zonas de acceso limitado. En el caso del Promontorio Ray, sería el resto del ASPA de Byers cuyo acceso es de unos pocos científicos al año. En estas zonas la presencia humana aunque limitada conllevaría al menos una pequeña carga de agentes externos al ASPA que podrían ser trasmitidos indirectamente a las zonas santuario. Por ello debe preguntarse si las barreras de protección marcadas por el hombre son funcionalmente validas como barreras para la naturaleza. Por otro lado, aparecen a una mayor distancia zonas de libre tránsito, con mayor carga humana que también pueden trasmitir los agentes externos a estos espacios. Seria por ejemplo la zona de visita de Punta Hannah (a 30 Km) o la Base Española Juan Carlos I (a unos 40 Km). Es cierto que parece difícil pensar que las formas de resistencia lleguen hasta ahí desde estos puntos u otros más lejanos. Pero es una posibilidad que debe ser evaluada y así nos planteamos ¿cuál es la distancia de seguridad? Finalmente señalar que agentes naturales y antrópicos pueden actuar como vectores de dispersión (aves marinas, basura flotante) superando estas barreras. Pese a todas inquietudes por resolver podemos decir que la medida de declaración de zonas santuario inviolables dentro de las ASPAs sigue el principio de precaución ante el desconocimiento sobre la carga de bioinvasiones microbiológicas. Y por tanto es una solución preventiva que debe potenciarse a falta de tener un conocimiento más claro sobre la dispersión de los microorganismos.

5.1.3 Las perturbaciones a fauna por la continua actividad humana

Otro elemento habitual de las visitas o expediciones en tierra es la interacción con la fauna local. Por la ausencia de vertebrados puramente terrestres la mega fauna en tierra queda relegada únicamente a los mamíferos y aves marinas. Aunque desarrollan gran parte de su actividad en el océano eventos clave de su ciclo de vida suceden en tierra. La reproducción, cría, muda y reposo son los más frecuentes. La visita a colonias de pingüinos es una de las actividades más frecuentes realizadas por los turistas en la Antártida. La llegada de visitantes a las colonias puede perturbar la conducta de los animales y tener efectos sobre la salud de individuos y sobre la dinámica de poblaciones. En el caso de las aves las colonias de pingüino alojan miles de individuos y por su singularidad son objeto de numerosas visitas. La visita masiva a colonias de aves puede perturbar su dinámica natural. En el capítulo 4.3 observamos que la interacción con los pingüinos tiene efectos medibles en su biología. La organización de las visitas es clave para minimizar la interferencia con la dinámica de las aves. La visita a las colonias requiere de la definición de una serie de elementos clave en la organización para minimizar las molestias a los individuos. En primer lugar el punto de desembarco y recogida de visitantes, en segundo lugar el trazado del recorrido (periférico/interno, parcial/total), en tercer lugar la cohesión del grupo (dispersos/ en fila) y finalmente la fase de los animales (p.e. cría, muda). Estos son los factores principales a tener en cuenta. Para ilustrar la problemática se detallan a continuación una serie de ejemplos potencialmente conflictivos observados en campo.

- Colonias con visitantes turísticos. En la Isla Decepción la pingüinera de pingüino barbijo en Morro Baily presenta una forma de anfiteatro con una salida al mar en cuello de botella. Este punto es a su vez el sitio de desembarco del turismo al espacio. Así una colonia de más de 100.000 individuos es toda ella susceptible de ser perturbada. Actualmente existen datos que indican una caída en las poblaciones de Baily Head si bien esto no puede ser directamente atribuida al turismo (Naveen et al. 2012). En la Isla Barrientos el sitio de desembarco en la isla se produce en la playa de salida al mar de la colonia de pingüino papúa. Si bien esta playa es algo más abierta (no más de 200 metros) la colonia es mucho menor (en torno a 5.000 individuos) y se encuentra mucho más próxima a la costa. El recorrido de la visita en tierra no aparece definido en este primer tramo y se produce una inmersión en la propia colonia con una interacción directa. Frente a éstas las colonias de petrel de la isla, mucho menos numerosas y como tal vulnerables, están protegidas, con cierre de senderos y evitando en todo momento acercarse a ellas a menos de 100 metros. En la Bahía Walkers el desembarco a tierra en la Punta Hannah está prohibido según las directrices de visita para proteger la colonia de forma que los turistas acceden a la colonia por la playa sur. La salida al mar no está comprometida en este lugar. En cuanto a la propia colonia la ruta de visita entra por el suroeste y atraviesa la colonia entre las roquerías. Estas normalmente tienen una separación entre sí proporcionando espacio suficiente para el paso a distancia de los turistas, no obstante debemos tener en cuenta el ciclo de la colonia ya que en determinadas etapas como la muda la organización espacial se pierde y es mucho más difícil evitar la proximidad con los animales.

Tal como vimos en el capítulo 4.3 existen indicios de que la presencia humana incide sobre la salud de las aves, y en mayor medida cuanto mayor interacción con los individuos. Queda por conocer como se traduce esto en su ecología poblacional. Ante la falta de un conocimiento claro sobre los efectos de las visitas a las pingüineras debe plantearse el principio de precaución. El trazado debe plantearse de forma que perturbe la menor cantidad de animales, por ejemplo realizando un rodeo periférico, que a su vez excluya una buena parte de la colonia centrándose en unas pocas roquerías (sub-colonias) más aisladas y evitando las rutas de los animales. De esta forma se puede hacer un seguimiento de la salud de los individuos en las zonas más expuestas y determinar si las visitas están impactando a los animales. También ha de tenerse en cuenta la fase en que se encuentra la colonia y atender a sus condiciones para gestionar las visitas. Durante la muda los animales se encuentran dispersos y es más fácil molestar a individuos sueltos siendo recomendable no realizar rutas internas. La huida de los individuos puede generar una cascada de movimientos, multiplicada por el número de personas caminando, hasta abrir un paso para las personas. En fase de cría los animales se encuentran concentrados en las roquerías y son potencialmente más susceptibles. Su distancia de huida es más reducida ante la defensa del nido. Aunque la visita puede atravesar más fácilmente la colonia entre roquerías debe evitar a toda costa las rutas animales y acercarse a los individuos cuidando los nidos. Todos estos aspectos han de ser incorporados a las directrices de visita. Igualmente ha de valorarse la necesidad de cerrar temporalmente estos espacios durante las fases vulnerables. Asimismo son necesarios estudios científicos dedicados que aporten un conocimiento preciso sobre los efectos que conllevan las visitas.

- Colonias con investigadores En el caso de los científicos la finalidad de las visitas a colonias es su estudio y tiene unos objetivos que implican una mayor interacción. La regulación de la interacción es también más estricta. El manejo de los animales queda regulado por un permiso de las autoridades del PNA responsable. Los mismos principios anteriores serian aplicables para este grupo: evitar entradas y rutas animales así fases vulnerables todo ello salvo bajo justificación de la necesidad para la propia investigación. Es igualmente recomendable trabajar sobre una sub-colonia pre-seleccionada parcializando los posibles molestias en la colonia. Esto es especialmente relevante en caso de trabajos continuados durante largos periodos. Además permite llevar a cabo un seguimiento de los posibles efectos negativos de la propia investigación.

Como ejemplo representativo en la Punta Vapor en Isla Decepción se lleva estudiando la colonia de pingüino barbijo desde hace mas de 20 años. La entrada es siempre por tierra, por un sendero desde el interior, eliminando las rutas de salida/entrada de animales de la colonia y los accesos al mar. Asimismo la investigación se ha centrado en las roquerías periféricas al norte de la colonia. De esta forma, sólo una péquela parte de la colonia de unos 30.000 individuos sufre realmente la presión de las actividades científicas. Igualmente es posible realizar un seguimiento de las roquerías investigadas. Las mediciones de corticosterona en pluma van en la dirección de un efecto de acostumbramiento en base a los niveles de estrés (capitulo 4.3). Sin embargo, los estudios sobre ecología de poblaciones no muestran un efecto atribuible a la presencia humana en estas sub-colonias (Barbosa et al. 2012). De tal forma podemos decir que los efectos biológicos detectados actualmente no tienen un efecto ecológico apreciable. Por ello, podemos concluir que el estudio científico prolongado en colonias con manejo de individuos tiene un efecto inevitable en los individuos, que debe ser evaluado de antemano y minimizado en campo para no tener consecuencias poblacionales, que han de ser vigiladas por medio de un seguimiento. De tal forma es viable un estudio a largo plazo. Debe señalarse que el estudio científico de las colonias aporta un conocimiento clave para su conservación y su disfrute. Así los fines científicos, en ocasiones percibidos como nocivos, son fundamentales para los intereses recreativos y de conservación.

5.2 RETOS PARA LA CONSERVACION EN LA ANTÁRTIDA

5.2.1 La necesidad de cuantificar las presiones

Las estrategias subsiguientes en próximos apartados para la conservación de los sistemas terrestres precisan del conocimiento de dos factores fundamentales: la carga de presión externa y la resiliencia propia del sistema. La presión humana en la Antártida terrestre se debe fundamentalmente a científicos y turistas. En el caso de los turistas gracias a la IAATO existe un buen conocimiento sobre la dispersión y el número anual de visitas (Pertierra et al. 2011). En el caso de los científicos esta información se recoge en el sistema EIES. Una diferencia notable de los científicos con los turistas es que los primeros pueden acceder prácticamente a cualquier espacio del continente, mientras que los segundos quedan relegados a una serie de sitios de visita, aunque su número y ubicación varia ligeramente cada año. En el caso de los científicos la mayor diferencia es que pueden acceder con un permiso a zonas protegidas. En los turistas no se permite el acceso salvo en el caso de ASPAs históricas. Como vimos en el capítulo 4.4 la concentración de científicos en ASPAs es muy variable. Su número es más reducido que en el caso de los turistas, pero su tiempo de estancia promedio suele ser mucho mayor (capitulo 4.5). El sistema EIES proporciona información del uso anual de la red de espacios protegidos en términos de permisos otorgados a investigadores pero carece de información sobre el tiempo total de estancia. Información necesaria para establecer una carga de presión acumulada. Asimismo no todas las naciones proporcionan la información necesaria impidiendo cuantificar la carga de presión total. Es fundamental el cumplimiento del sistema de intercambio de información ambiental EIES para la gestión efectiva de las zonas protegidas. Como veremos en los siguientes apartados esta información nos permite realizar evaluaciones de impacto, analizar las estrategias optimas de conservación y construir escenarios de futuro. En el capítulo 4.5 se exponen ejemplos de análisis que se podrían hacer disponiendo de toda la información. Asimismo se muestran las inconsistencias observadas en la interpretación e implementación del sistema de permisos así como el bajo grado de cumplimiento actual, que debería ser del 100%. Siendo una cuestión de gran importancia para la protección ambiental los resultados de este análisis se presentarán en forma de documento informativo a la próxima reunión ATCM/CEP (Anexo adjunto).

5.1.2 Evaluación del coste ambiental global de la presencia humana en la Antártida

Es necesario tener una visión global de la huella humana en la Antártida, sentando la base para el seguimiento de impactos acumulativos. La distribución de bases científicas, sitios de visita turística, restos históricos o estaciones remotas conforma una red de elementos humanos que va estrechando el cerco sobre los ambientes vírgenes. Hughes et al. (2011) muestra como un solo programa nacional de investigación ha sido capaz por sí mismo de abarcar todas la extensión de la Península Antártica. La suma espacial de actividades humanas reduce los valores estéticos y la extensión de ambientes de naturaleza salvaje propiamente de la Antártida (Summerson et al. 2012). A través de las presiones espaciales tenemos una idea de la intensidad de las actividades. Ante una presencia humana reiterada el impacto humano creciente asociado debe ser controlado. Una estrategia es definir y limitar zonas de sacrificio en aquellos lugares transformados, por ejemplo a través de senderos en sitios de visita (Tejedo et al. 2013), o en el entorno de las bases científicas y campamentos. Sin embargo las instalaciones, típicamente modulares tienden a crecer, y las redes de senderos se diversifican. Por lo que las zonas de sacrificio deben tener límites estrictos para frenar su crecimiento, tanto espacial como de uso. También cabe preguntarse el coste material global de tal presencia, dado que el transporte a estas zonas remotas supone grandes inversiones energéticas y de materiales, que pueden ser estimadas en forma de emisiones de CO_2. Farreny (2010) obtiene datos sobre los elevados costes de CO_2 por persona de la actividad turística, y el capítulo 4.5 hace lo propio sobre investigadores. Ante tal magnitud de costes, potenciada de manera progresiva por el número creciente de visitantes antárticos deben buscarse mecanismos de optimización y reducción de costes por persona, maximizando por el contrario los beneficios de tal presencia.

- Coste ambiental de los campamentos de investigación. Los campamentos actúan como centros locales de distribución de investigación. La huella ecológica se centra en el entorno de los campamentos. En un ASPA marcadamente internacional es especialmente necesaria la coordinación debido a la gran cantidad de PNA implicados (Benayas et al. 2013). Una estrategia actual que se puede aplicar al respecto es reutilizar zonas de acampada previas. Esto tiene la ventaja de no dispersar los impactos, especialmente en ASPAs con numerosas visitas a lo largo del tiempo. En cambio tiene el problema de concentrarlos, limitando la capacidad de recuperación. En espacios con apenas visitas parece más factible la primera opción, de forma que se borre rápidamente la huella. Sin embargo, las huellas pueden perdurar durante mucho tiempo y en sitios de gran ocupación o de baja sensibilidad es preferible la segunda. El grado de ocupación es fácil de determinar atendiendo al capítulo 4.5. En cambio para interpretar la sensibilidad hay que atender a los capítulos 4.1, 4.2 y 4.3 así como a otros aspectos muchos aspectos. El capitulo 4.6 trata de recogerlos e integrarlos para formular estrategias globales. El establecimiento de campamentos en zonas protegidas es la construcción máxima permitida. La elaboración de los planes de gestión recoge las actividades permitidas. El establecimiento de campamentos dentro de las ASPAs supone la máxima concentración de impactos permitida en el espacio. Por ello debe tener especial cuidado en su ubicación. Por un lado debe proveer todos los servicios necesarios para la estancia de investigadores. Por otro lado debe situarse en una zona de baja vulnerabilidad de forma que los impactos sean minimizados. Actualmente los planes de gestión de las ASPAs son muy diversos en cuanto a las provisiones para el establecimiento de campamentos. Desde la designación de zonas especificas de acampada, pasando por unas directrices generales en otros casos, a la ausencia de toda mención al respecto. Debido a la importancia que supone para el entorno es necesario revisar y completar los planes de gestión en torno a este aspecto.

5.2.3 Los escenarios de futuro para la gestión sostenible

La singularidad geopolítica de la Antártida condiciona una gestión consensuada en la que el éxito de la aplicación de medidas ambientales efectivas requiere de una diplomacia. La efectividad de las medidas de protección antártica dependen de tres fases básicas en su desarrollo. En primer lugar se da una fase de reunión y planificación, en la que en base al conocimiento recibido por informes anuales e investigaciones aportadas se elaboran y aprueban de manera comunitaria entre los delegados de programas nacionales y o comités de protección las resoluciones y medidas necesarias para garantizar la conservación. En una segunda fase de interpretación los programas nacionales interpretan y aplican estas decisiones dentro de su logística. Finalmente en una tercera fase de implementación las medidas son adoptadas generando un mayor o menor efecto dependiendo de diversos factores, entre ellos la aceptación y compromiso de los grupos implicados. El ciclo se cierra con nuevos informes y estudios científicos recabados y aportados en la siguiente fase de reunión. Así, la investigación científica sustenta la toma de decisiones con un aprovisionamiento de información. La formula de éxito en la protección por tanto deberá contener tanto un asesoramiento científico de calidad (monitoreo ambiental) como un alto grado de cohesión para la aplicación (acuerdo político y aceptación social). La ausencia de ambos en espacios de intensa actividad humana conduce a la confluencia de problemas ambientales y tensiones institucionales, tal como muestra Braun et al. 2012 sobre la Península Fildes. En este espacio la intensa actividad humana facilita la entrada de especies no nativas, como *Poa annua* (Olech et al. 1996, Molina-Montenegro et al. 2012), y muy recientemente *Juncus bufonios* (Cuba-Díaz et al. 2012).

- Cuestión práctica: gestión de intereses opuestos en un ASMA. La Isla Decepción (ASMA 4) contiene todos los valores de protección designados en la Antártida. Su carácter volcánico resulta en grandes valores paisajísticos. El vulcanismo y los procesos asociados tienen un gran valor científico a la vez que estas condiciones anómalas dan lugar a valores naturales de conservación en relación a su biología singular. La presencia de bases abandonadas y una antigua factoría ballenera tienen un valor histórico. Y en conjunto, estos valores generan un valor educativo que da lugar a numerosas visitas turísticas. De tal forma la isla Decepción presenta grandes presiones humanas y por ello grandes retos de protección. La gran cantidad de intereses contrapuestos ha formulado la creación de un ASMA que busca coordinar todos estas actividades, gestionar los potenciales conflictos entre ellas y asegurar el buen estado de conservación de la isla. Sin embargo, las previsiones de crecimiento de actividades humanas así como importantes agentes de cambio como el calentamiento regional o las bioinvasiones amenazas este modelo actual. Así, el modelo actual continuista funciona en el presente con notable adecuación sin embargo queda comprometido por mayores cargas de presión en el futuro que de manera acumulativa van degradando y transformando los ecosistemas. Un escenario opuesto en el que se paralicen las actividades humanas evitaría estas perturbaciones sobre los valores naturales, históricos y paisajísticos pero agotaría los valores científicos y educativos. Adicionalmente este escenario tendría una muy baja aceptación entre los grupos interesados con lo que la actuación tendría difícilmente una efectiva implementación. Entre medias de estos escenarios se desarrollan modelos con alternativas con una protección adicional a la presente sin renunciar a estos valores. Son aquellos que se basan en el monitoreo ambiental y el desarrollo de protocolos específicos de reducción de impactos cuando el monitoreo detecta un exceso en la capacidad de carga de los ecosistemas y/o una degradación de los mismos. Tienen la ventaja además de una mayor aceptación entre agentes interesados y un cierto compromiso para la implementación. La existencia del sistema ASMA y su grupo de gestión así como el asesoramiento científico son piezas clave en el desarrollo de estos modelos. Finalmente estos modelos deben contemplar otros escenarios en los que la protección adicional no consiga evitar la degradación y sea necesaria una actuación más tajante. Esta actuación iría encaminada a limitar las presiones por actividades humanas, a través de cierres temporales o cupos de visitantes. Esta alternativa para asegurar la protección es de más difícil aceptación, por ello la diplomacia en busca de acuerdos tiene un papel fundamental. El análisis MEA empleado en Isla Decepción permite construir mecanismos de gestión ante problemas ambientales emergentes. Así se postula el empleo de modelos intermedios de gestión en isla Decepción con integración de distintas alternativas (protocolos de reducción de impactos combinado con minimización de presiones). Así la Isla Decepción es un ejemplo de área común en la que es especialmente importante tanto la monitorización como la diplomacia para la protección ambiental. Frente a casos como la Bahía Fildes (Braun et al. 2012) la Isla Decepción dispone de los elementos necesarios para afrontar los retos ambientales sugeridos por estos autores, por ello se sugiere emplear esta infraestructura generada a través de las estrategias expuestas para asegurar los compromisos de conservación de la isla.

5.3 HACIA UNA ESTRATEGIA GLOBAL DE PROTECCIÓN

La conservación futura de la Antártida encuentra distintas retos para su protección, muchos de los cuales son equiparables a los mayores retos del resto de continentes pese a ser tratado aparte (véase Sutherland et al. 2009). A su vez Chown et al. 2012 ofrece una recopilación de retos de conservación futura de la Antártida destacando el incremento y diversificación de actividades humanas en la Antártida así como la creación de establecimientos permanentes, el agotamiento mundial de recursos naturales y la sobre-explotación local de los recursos marinos antárticos, unido todo ello a los efectos regionales del cambio climático y medioambiental. Señalar por tanto que las presentes presiones e impactos se verán progresivamente incrementados en el futuro aumentando la transformación de los sistemas. Asimismo otros impactos hoy poco conocidos o invisibles tras el avance en el conocimiento de los sistemas tendrán un papel más relevante en el futuro (Sutherland et al. 2012), como pueda ser la incógnita sobre las perturbaciones de biodiversidad microbiológica en el caso antártico. Finalmente tal vez el mayor reto se halla en el conflicto de intereses dentro del marco del Tratado Antártico, que dificulte los procesos de reunión, interpretación e implementación para la efectiva protección ambiental. Las distintas visiones de la Antártida, desde las más utilitaristas a las mas idealistas, aparecen confrontadas dificultando la puesta en marcha de la gestión ambiental apropiada para afrontar estos cambios, siendo necesaria una estrategia integradora y proactiva (Tin et al. 2012). A continuación se relatan los principales retos disgregados por los distintos intereses legítimos enfrentados en la Antártida.

Retos derivados de intereses conservacionistas. Un primer grupo de intereses son aquellos que buscan como finalidad en sí misma la preservación de los valores naturales existentes. Una cuestión fundamental detectada en el desarrollo de este trabajo y que debe revisarse en el futuro es la organización del sistema de áreas protegidas con una visión estratégica global. Actualmente solamente unos 3.000 Km^2 de la Antártida se encuentran protegidos, siendo su mayoría marinos o glaciares. Debe señalarse que únicamente la extensión de las infrecuentes zonas libres de hielo es ya de unos 50.000 Km^2. Por otra parte los valores que se protegen derivan del desarrollo histórico del sistema (Hughes et al. en prensa) a raíz de propuestas de países constitutivos. No responde a una visión global en la que todos los valores de la Antártida queden recogidos por igual. Muchos de ellos fueron designados para proteger colonias de aves marinas, obviándose muchos otros elementos de los ecosistemas. Igualmente la distribución es muy irregular como vimos en el capítulo 4.4. En un extremo aparecen grandes concentraciones de ASPAs en zonas con destacada presencia humana. En el otro extremo aparecen grandes extensiones libres de ASPAs. Puede discutirse que no precisan de un nivel de protección especial ya que no hay apenas presencia humana en ellas. Sin embargo no por ello deben dejar de ser valoradas. Es importante definir criterios globales para la designación de las ASPAs. Incluyéndose aquí todas las regiones y ambientes que representan unos valores singulares o representativos. En el caso de aquellas zonas que se encuentren con una amenaza directa la formula de ASMA parece más apropiada protegiendo unos valores que si bien no son especialmente singulares son igualmente de gran interés científico, educativo, histórico o paisajístico. En el primer caso (ASPA) se trataría de elevar a la máxima categoría de protección cada uno de los valores y con la extensión necesaria para garantizar su conservación. Así son perfectamente adecuadas todas estas ASPAs con colonias de aves si con ello se está protegiendo la supervivencia la/s especie/s presentes. Pero de igual modo se han de proteger igualmente otros valores en la medida optima para su conservación. En el segundo caso (ASMA) se trata de regular y coordinar las actividades e intereses en zonas con ecosistemas amenazados (Braun et al. 2012). Por ello es llamativo la ausencia de mayor numero de ASMAs en zonas con gran aglomeración de bases y sitios de visita, como son las Shetland del Sur por ejemplo. Braun et al. (2012) muestra las dificultades para el establecimiento de nuevos ASMAs a través del caso de Península Fildes en Isla Rey Jorge. En cambio son las ASPAs las más frecuentes en esta región. Es necesario redefinir el mapa global de zonas de protección/gestión especial. En el primer caso con un sentido natural orientado a valores representativos y en el segundo con una ordenación humana en base a la carga de presión. Actualmente el sistema de áreas protegidas es en gran medida resultado del desarrollo histórico de los NAPs y no tanto derivado de un orden natural y por tanto imperfecto en este sentido para una protección efectiva (Hughes et al. en prensa). Por otro lado los valores paisajísticos e intrínsecos se ven amenazados por el desarrollo de las actividades humanas legitimas (Summerson et al. 2012), en situación de conflicto debe definirse que valores priorizar.

Retos derivados de intereses científicos. Por su parte un segundo grupo de intereses son aquellos que buscan ampliar el conocimiento del mundo que nos rodea para beneficio de la humanidad. Un importante reto de investigación es el entendimiento de los procesos ecológicos y la resiliencia de los ecosistemas ante problemas ambientales, en particular aquellos que afectan a las cadenas alimentarias antárticas desde su base como la sobrepesca de krill, o el efecto del cambio climático en la producción algal (Smetacek & Nicol 2005). Estos factores son igualmente relevantes para el estado de las comunidades terrestres frente a impactos directos locales. Por ejemplo en las colonias de aves marinas la exclusión entre factores locales y regionales debe entenderse para comprender la caída de poblaciones (Naveen et al. 2012). Actualmente los nuevos programas SCAR Ant-ECO y Ant-ERA se encaminan a arrojar conocimiento sobre estos aspectos. En el ámbito de los programas nacionales de investigación los beneficios científicos se deben maximizar para optimizar la investigación, reduciendo el coste para otros valores. Los objetivos de investigación deben ser fundamentados, relevantes y difundidos para tener justificación. Pero igualmente la obtención de resultados no dirigidos, contribuciones al monitoreo básico de los ecosistemas y autoevaluación ambiental de la propia investigación añaden beneficios a la investigación más allá de los objetivos primarios. Por otro lado los impactos se deben minimizar a través de una gestión específica para reducir el coste ambiental. En este caso el apoyo logístico tiene un papel fundamental (véase como ejemplo Braun et al. 2012). Finalmente como hemos visto es muy necesario el asesoramiento científico dentro del marco del tratado antártico, de forma que la toma de decisiones en la arena política de las reuniones anuales este basada en información objetiva y actualizada.

Retos derivados de intereses recreativos. Un tercer grupo de intereses legítimos son aquellos que buscan el disfrute y enriquecimiento individual a través de la experiencia personal. Estos últimos, principalmente asociados al turismo regulado mayoritariamente por la IAATO, encuentran sus propios retos de gestión y gobernanza al pertenecer la Antártida al concepto de áreas comunes en la que confluyen distintos intereses con un gobierno internacional (Lamers et al. 2012). En primer lugar cabe preguntarse qué sitios deben permitir el desarrollo de estas actividades, y bajo qué condiciones. Actualmente el sistema de directrices de visita marca la pauta de comportamiento en sitios turísticos (Nueva Zelanda, 2009). Sin embargo no hay un proceso claro de designación de sitios de visita ni de condiciones para su desarrollo y distribución (Lynch et al. 2009). La notable ausencia de monitoreo directo de estas actividades ha llevado a construir estrategias de vigilancia alternativas, véase Roura 2012. Ante una capacidad de acogida creciente y deseo de conocer ilimitado que no pone topes al número de visitantes cabe preguntarse cuáles son los limites para esta actividad. Aquí resurge el concepto de capacidad de carga, al menos en relación a definir limites en cuestiones de número de personas, si bien Roura (2012) señala la problemática de la variedad de comportamientos. Por ello es igualmente necesario perfilar qué papel deben tener los visitantes recreativos en el continente antártico y elaborar una estrategia de educación ambiental y de participación que los integre de manera amistosa dentro del panorama antártico (Roura 2012, Lamers et al. 2012). Finalmente cabe preguntarse la estructura administrativa para dirigir tal responsabilidad, sugiriéndose una estrategia colectiva e imparcial en la regulación del turismo antártico (Lamers et al. 2012).

Conclusiones. En síntesis, la contraposición de valores en la Antártida supone un dilema de prioridades entre el interés conservacionista, el interés científico y el interés educativo/cultural o recreativo. Para construir una estrategia global de protección deberán resolverse de manera anticipada los distintos problemas derivados y cuestiones previamente descritas, resumidos nuevamente de forma sucinta en:

- Establecimiento del estado y resiliencia de los ecosistemas
- Gestión específica frente a impactos acumulativos
- Lucha contra la perdidas de hábitat y de biodiversidad
- Adaptación a los riesgos adicionales derivados del cambio climático
- Representatividad en la protección de los ecosistemas
- Monitorización y vigilancia ambiental
- Justificación y calidad de la ciencia
- Cuantificación y coordinación de las presiones científicas
- Optimización de protocolos logísticos
- Conflicto y priorización de valores
- Delimitación de espacios recreativos
- Definición de capacidades de carga
- Zonificación y directrices de uso
- Educación ambiental y participación social
- Gestión y gobernanza.

De tal forma, el presente trabajo trata de poner en alza el conocimiento adquirido a lo largo del desarrollo de la investigación de Tesis Doctoral para abordar estas cuestiones.

BIBLIOGRAFIA DEL CAPÍTULO

ATS (ANTARCTIC TREATY SECRETARIAT). 2012. The Antarctic Treaty; Documents; Environmental Protocol. URL: http://www.ats.aq/documents/recatt/Att006_e.pdf). Visit ado poor ultimo vez en Nov. 2012.

Ayres, E., Nkem, J.N., Wall, D.H., Adams, B.J., Barrett, J.E., Broos, E.J., Parsons, A.N., Powers, L.E., Simmons, B.L. & Virginia, R.A. 2008. Effects of human trampling on populations of soil fauna in the McMurdo Dry Valleys, Antarctica. *Conservation Biology,* **22**, 1544-1551.

Barbosa, A., Benzal, J., De Leon, A., & Moreno, J. (2012a). Population decline of chinstrap penguins (Pygoscelis antarctica) on Deception Island, South Shetlands, Antarctica. *Polar Biology, 35*(9), 1453-1457.

Braun C, Mustafa O, Nordt A, Pfeiffer S, & Peter H-U (2012) Environmental monitoring and management proposals for the Fildes Region, King George Island, Antarctica. *Polar Research*.

Benayas J, Pertierra RL. Tejedo P. Bermudez O. Lara F. Hughes KA. & Quesada A. (2013). A review of scientific research trends within ASPA 126 Byers Peninsula, South Shetland Islands, Antarctica. *Antarctic Science,* doi:10.1017/S0954102012001058.

Clarke, A. and Harris, C.M. (2003) Polar marine ecosystems: major threats and future change. Environmental Conservation 30(1), 1-25.

Chown SL*, et al.* (2012) Challenges to the Future Conservation of the Antarctic. *Science* 337(6091):158-159.

Cowan, D.A. Chown, S.L. Convey, P. Tuffin, M. Hughes, K.A. Pointing, S. Vincent W.A. 2011. Non-indigenous microorganisms in the Antarctic: assessing the risks Trends in Microbiology, Volume 19, Issue 11, pp. 540-548.

Cuba-Díaz M, Max Troncoso JM, Cordero C, Finot VL & Rondanelli-Reyes M (2012) *Juncus bufonius*, a new non-native vascular plant in King George Island, South Shetland Islands. Antarctic Science, Short Note. http://dx.doi.org/10.1017/S0954102012000958

Ecuador y España (2012) Revisión de las directrices para sitios visitados: Isla Barrientos (Islas Aitcho). Documento de trabajo 59 presentado a la 35º Reunión Consultiva del Tratado Antártico (ATCM XXXV) en Hobart, Australia, del 11 al 20 de Junio de 2012.

España (2010) El posible impacto humano en isla Decepción. Documento informativo 20 presentado a la 33º Reunión Consultiva del Tratado Antártico (ATCM XXXIII) en Punta del Este, Uruguay, del 3 al 14 de Mayo de 2010

Ensminger, J.T., McCold, L.N. and Webb, J.W. (1999) Environmental impact assessment under the National Environmental Policy Act and the Protocol on Environmental Protection to the Antarctic Treaty. Environmental Management 24(1), 13-23.

Farreny, R., Oliver-Solà, J., Lamers, M., Amelung, B., Gabarrell, X., Rieradevall, J., Boada, M. & Benayas, J. 2011. Carbon dioxide emissions of Antarctic tourism. *Antarctic Science*, **23**, 556-566.

Frenot, Y., Chown, S.L., Whinam, J., Selkirk, P., Convey, P., kotnicki, M. & Bergstrom, D. 2005. Biological invasions in the Antarctic: extent, impacts and implications. *Biological Reviews*, **80**, 45-72.

Gremmen, N.J.M. Smith, V.R. & Van Torengen, O.F.R. 2003. Impact of trampling on the vegetation of Subantarctic Marion Island. *Arctic, Antarctic, and Alpine Research*, **35**, 442-446.

Hughes, K.A. & Convey, P. 2010. The protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. *Global Environmental Change,* **20**, 96-112.

Hughes, K.A, Fretwell p. Rae j. Holmes k. & Fleming A. 2011 Untouched Antarctica: mapping a finite and diminishing environmental resource. *Antarctic Science*, **23**, 537-548.

Hughes KA**.** Pertierra RL**.** & Walton D. (En prensa) Management of Antarctic Specially Protected Areas: are our environmental practices adecuate? *Environmental Science and Policy*

Quesada, A., Camacho, A., Rochera, C. & Velázquez, D. 2009. Byers Peninsula: A reference site for coastal, terrestrial and limnetic ecosystem studies in maritime Antarctica. *Polar Science,* **3**, 181-187.

Millennium Ecosystem Assessment (MEA). 2005. Ecosystems and human well-being: synthesis. Island Press, Washington, D.C.

Molina-Montenegro, M. A., Carrasco-Urra, F., Rodrigo, C., Convey, P., Valladares, F., & Gianoli, E. (2012). Occurrence of the Non-Native Annual Bluegrass on the Antarctic Mainland and Its Negative Effects on Native Plants. *Conservation Biology, 26*(4), 717-723

Nash, S.B. (2011) Persistent organic pollutants in Antarctica: current and future research priorities. Journal of Environmental Monitoring 13(3), 497-504.

Naveen, R., Lynch, H.J., Forrest, S., Mueller, T. and Polito, M. (2012) First direct, site-wide penguin survey at Deception Island, Antarctica, suggests significant declines in breeding chinstrap penguins. Polar Biology 35(12), 1879-1888.

New Zealand 2009. Joint VISTA_Oceanites Antarctic Project. Information Paper 37. XXXII Antarctic Treaty Consultative Meeting. 6_17 April, Baltimore.

Lamers, M., Liggett, D. and Amelung, B. (2012) Strategic challenges of tourism development and governance in Antarctica: taking stock and moving forward. Polar Research 31.

Lee, J.E. and Chown, S.L. (2009) Breaching the dispersal barrier to invasion: quantification and management. Ecological Applications 19(7), 1944-1959.

Lynch, H.J., Crosbie, K., Fagan, W.F. & Naveen, R., 2009. Spatial patterns of tour ship traffic in the Antarctic Peninsula region. *Antarctic Science,* 22(2), pp. 123-130

Ochyra, R., R.I. Lewis & H. Bednarek-Ochyra. (2008). *The Illustrated Moss Flora of Antarctica*. Cambridge University Press, 685 pp.

Olech M (1996) Human impact on terrestrial ecosystems in west Antarctica. Proc NIPR Symp Polar Biol 9:299–306

Pertierra RL. Tejedo P. Benayas J. & Boada M. (2011) Evolución del turismo en la Antártida. *Quercus, 300* Febrero 2011.

Reino Unido, Chile y España (2010) Plan de gestión de la Zona Antártica Especialmente Protegida № 126, península Byers, isla Livingstone, islas Shetland del Sur. Documento de trabajo 43, presentado a la 33º Reunión Consultiva del Tratado Antártico (ATCM XXXIII) en Punta del Este, Uruguay, del 3 al 14 de Mayo de 2010

Reino Unido y España (2012) Colonisation status of the non-native grass Poa pratensis at Cierva Point, Antarctic Peninsula. Documento informativo 13 presentado a la 35º Reunión Consultiva del Tratado Antártico (ATCM XXXV) en Hobart, Australia, del 11 al 20 de Junio de 2012

Roura, R. M. (2012). Being there: examining the behaviour of Antarctic tourists through their blogs. *Polar Research*.

Tejedo, P., Pertierra L.R,, Justel, A., Benayas, J. Convey, P. & Quesada, A. 2013. Trampling on Maritime Antarctica: Can soil ecosystems be effectively protected through existing codes of conduct? *Polar Research*, 31.

Tin, T., Fleming, Z.L., Hughes, K.A., Ainley, D.G., Convey, P., Moreno, C.A., Pfeiffer, S., Scott, J. & Snape, I. 2009. Impacts of local human activities on the Antarctic environment. *Antarctic Science*, **21**, 3-33.

Tin T, Liggett D, & Maher PT (2012) Foreword: The complex business of managing human activities and protecting the environment of the polar regions. *Polar Research* 31

Smith, R.I.L. & Simpson, H.W. 1987. Early nineteenth century sealer refuges on Livingston Island, South Shetland Islands. *British Antarctic Bulletin*, **74**, 49-72.

Sutherland, W.J., Adams, W.M., Aronson, R.B., Aveling, R., Blackburn, T.M., Broad, S., Ceballos, G., Cote, I.M., Cowling, R.M., Da Fonseca, G.A.B., Dinerstein, E., Ferraro, P.J., Fleishman, E., Gascon, C., Hunter, M., Hutton, J., Kareiva, P., Kuria, A., MacDonald, D.W., MacKinnon, K., Madgwick, F.J., Mascia, M.B., McNeely, J., Milner-Gulland, E.J., Moon, S., Morley, C.G., Nelson, S., Osborn, D., Pai, M., Parsons, E.C.M., Peck, L.S., Possingham, H., Prior, S.V., Pullin, A.S., Rands, M.R.W., Ranganathan, J., Redford, K.H., Rodriguez, J.P., Seymour, F., Sobel, J., Sodhi, N.S., Stott, A., Vance-Borland, K. and Watkinson, A.R. (2009) One Hundred Questions of Importance to the Conservation of Global Biological Diversity. Conservation Biology 23(3), 557-567.

Sutherland, W. J., Aveling, R., Bennun, L., Chapman, E., Clout, M., Cote, I. M., et al. (2012). A horizon scan of global conservation issues for 2012. *Trends in Ecology & Evolution, 27*(1), 12-18.

Summerson R & Bishop ID (2012) The impact of human activities on wilderness and aesthetic values in Antarctica. *Polar Research*.

Vaughan, D.G., Marshall, G.L., Connolley, W.L., Parkinson, C., Mulvaney, R., Hodgson, D.A., King, J.C., Pudsey, C.J. & Turner, J. 2003. Recent rapid regional climate warming on the Antarctic Peninsula. *Climatic Change,* **60,** 243-274.

Capítulo

6 Conclusiones

CONCLUSIONES

A continuación se resumen las principales aportaciones derivadas de la consecución de los trabajos de investigación sobre los objetivos específicos de la Tesis:

Sobre la investigación I. Protección de la vegetación terrestre ante el pisoteo. Las comunidades criptógamas compuestas por musgos y líquenes terrícolas se han mostrado muy vulnerables ante el pisoteo. Ante bajas presiones se produce una fuerte denudación de la cobertura (más del 50% de perdidas con menos de 200 pisadas). Asimismo, aspectos como la cantidad de agua, biomasa y la compactación del suelo se ven alterados según se incrementa la intensidad de uso. Dado que existe un elevado solapamiento entre actividades humanas y los ecosistemas terrestres antárticos para la reducción de impactos sobre éstos por el mero tráfico de personas deberá identificarse la sensibilidad de las comunidades vulnerables a ésta actividad y definir estrategias acordes a la carga de presión. Al respecto la estrategia básica sobre las comunidades de plantas criptógamas deberá consistir siempre en evitarlas, en caso de pisarlas irremediablemente de manera puntual dispersar el uso, o bien, ante una mínima frecuencia de uso, se deberá emplear un sendero de sacrificio para limitar el impacto generado.

Sobre la investigación II. Conservación de la biodiversidad vegetal a través del caso Poa pratensis. La especie no nativa establecida *Poa pratensis* se encuentra confinada al lugar de introducción. El desarrollo de las estructuras reproductoras se ve truncado por las condiciones ambientales locales, con temperaturas estival aún por debajo del requerimiento necesario para el desarrollo completo. Por el contrario el aumento del crecimiento vegetativo sugiere una progresiva adaptación al medio gracias a la existencia de condiciones paulatinamente más favorables. Las actividades humanas son un importante agente dispersor de propágulos, con poca incidencia hasta el momento en el caso de la *Poa pratensis.* El agravamiento del cambio climático sugiere un debilitamiento progresivo de las barreras naturales ante las bioinvasiones. Ante esta transformación y el previsible crecimiento de las actividades humanas se recomienda la erradicación de la planta antes de alcanzar un estado óptimo para la floración y dispersión.

Sobre la investigación III. Seguimiento de la salud de la mega fauna en tierra a través de colonias de pingüinos. Los estudios realizados muestran la gran dificultad para entender en su complejidad los efectos de la interacción por presencia del hombre en las colonias como un agente causante de perturbaciones. Los resultados se encaminan hacia una incidencia de la presencia humana en los niveles de estrés en los individuos, pero también la confluencia de factores naturales como el propio sexo, la ubicación espacial de las colonias, la presión depredadora o el tamaño de las poblaciones. Por ello ante las alarmas de caída general de poblaciones es necesario aplicar el principio de precaución limitando la interacción, particularmente en sitios de confluencia masiva, y desarrollar estudios adicionales que permitan esclarecer los efectos ecológicos de estos cambios fisiológicos.

Sobre la investigación IV. Evaluación del sistema de protección especial. Los resultados de esta investigación han mostrado la importancia del intercambio de información para la gestión ambiental ante la otorgación de cerca de 10.000 permisos de entrada a áreas protegidas en un periodo de 3 años. Existe un extenso incumplimiento en la presentación de informes (faltando cerca de un 35%) que limita en gran medida la gestión sobre estos espacios. Asimismo se ha detectado una gran irregularidad espacial y el crecimiento histórico desigual en torno a los valores de protección. Igualmente se ha constatado la confluencia de varios programas nacionales en un mismo área (hasta seis distintos en el ASPA 126) lo que constituye una superposición de huellas ecológicas de difícil gestión. Por ello se destaca la necesidad de integración de actividades para reducir los impactos.

Sobre la investigación V. Cálculo de la huella ecológica de la presencia humana a través de la investigación en un área protegida. Estos trabajos son indicativos de la importancia del monitoreo ambiental de actividades para analizar los costes de la investigación y construir estrategias de gestión ambiental. La huella de carbono ha mostrado ser un indicador del elevado coste de la investigación en áreas remotas, con cerca de 14 Toneladas de CO_2 eq. por viaje de investigador. A través del seguimiento de la huella por pisoteo en el espacio protegido se ha detectado la distribución espacial de impactos, pudiendo anticiparse los impactos resultantes y desarrollando de antemano estrategias de reducción de estos optimizando el uso. Finalmente se destaca la necesidad de evaluar los costes ambientales frente beneficios científicos de una manera sistemática.

Sobre la investigación VI. Construcción de estrategias de futuro en el área gestionada de Isla Decepción. En este estudio se han identificado los agentes de cambio y los escenarios de futuro de la isla como ejemplo de la dinámica de la transformación humana en enclaves de confluencia de distintos valores antárticos y grupos con intereses. Se ha detectado la necesidad de priorizar valores entre sí en situaciones de conflicto de intereses. Tres escenarios de futuro alternativos han sido construidos en base a las previsiones en la intensidad de uso, la degradación de los ecosistemas y el grado de cooperación internacional. En este contexto se proponen dos estrategias de protección (zonificación y estándares de protección) que permitan integrar un alto grado de conservación con un fuerte compromiso, aplicables al conjunto de espacios amenazados del continente.

A modo de conclusión final, señalar nuevamente el valor intrínseco adicional de la Antártida, y entenderlo como un ejemplo inspirador para la humanidad, situándolo en un referente de cooperación internacional, de conservación holística y de unión, respeto, entendimiento y convivencia con la naturaleza salvaje. De tal manera esta tesis trata de recoger el encomiable esfuerzo de muchas personas, durante muchas décadas y dar un paso más hacia consolidar ese futuro deseado.

RELACIÓN DE APÉNDICES

RESEARCH/REVIEW ARTICLE

Trampling on maritime Antarctica: can soil ecosystems be effectively protected through existing codes of conduct?

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Trampling impacts; environmental monitoring; low impact practices; soil resilience; soil penetration resistance; collembolan abundance.

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Abstract

Soil trampling is one of the most obvious direct negative human impacts in Antarctica. Through a range of experiments and field studies based on quantitative physical (soil penetration resistance) and biological (collembolan abundance) indicators, we evaluate the current codes of conduct relating to the protection of Antarctic soils from the consequences of pedestrian impacts. These guidelines include using, where available, established paths that cross vegetation-free soils. However, the effectiveness of this strategy is highly dependent on context. Limited intensity use—below 100 foot passes per year—produces small changes at the soil surface that can recover relatively rapidly, suggesting that the dispersal of activity across wider corridors may be the most appropriate option. However, for paths with a higher use level and those located in steep-sloped sites, it is desirable to define a single track, following stony or bouldery surfaces wherever possible, to keep the disturbed area to a minimum. It is clear that both environmental conditions and expected use levels must be taken into account in determining when and where it is more appropriate to concentrate or disperse human activities. Even though they may have performed satisfactorily to date, the increasing pressure in terms of numbers of visits for certain sites may make it necessary to revise existing codes of conduct.

Antarctica is a vast continent with an area around 14 000 000 km^2, but its terrestrial life is limited to only 0.34% of this area, including exposed nunataks, cliffs, and seasonally snow- and ice-free ground (Convey 2010), having a combined area of only ca. 44 000 km^2 (Convey et al. 2009). Terrestrial habitats can be considered as isolated "islands" separated by ice or ocean (Bergstrom & Chown 1999). Soils exposed during the austral summer are characterized by limited depth, low organic matter content, low biomass and primary production, limited availability of nutrients such as nitrogen and phosphate as well the entire range of trace elements, low water content approaching aridity in many cases, and slow decomposition rates (Thomas et al. 2008). These features make many Antarctic soils readily vulnerable to disturbance by human activities (Campbell et al. 1993). Unconsolidated soils with sandy pebble-gravel textures are very vulnerable to damage by pedestrian traffic. Foot tracks can be formed in these soils in a very short time and may remain visible for many years after the event (Campbell & Claridge 1987). In the Victoria Land Dry Valleys, Campbell et al. (1998) reported that tracks formed in sandy gravel soils after as few as 20 pedestrian transits remained visible up to 30 years later. The high fragility of the surface pavement and the absence of significant natural rehabilitation processes in this area underlie this long-lasting disturbance. Hodgson et al. (2010) similarly observed the continued presence of footprints in the Davis Valley, Pensacola Mountains, from a single visit over 50 years ago. Meanwhile, soils

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with a high surface boulder cover and/or a large particle-size fraction are the least sensitive (Campbell et al. 1998). Paths on these surfaces are less obvious, especially in the absence of clear slopes or areas of finer grained soil or mud. Regardless of soil type, it is recognized that ground surface damage through trampling by national operator staff and tourists visiting the region is one of the most obvious direct negative impacts of human presence in the Antarctic (Cessford & Dingwall 1998; Tin et al. 2009). In recent years, there has been an increase in the extent of activities (the "operational footprint") of both scientists and visitors across Antarctica, and an associated expansion and diversification of human activities (Stewart et al. 2005). As a result, the interest in and attention paid to human impacts on the Antarctic environment is growing (Tin et al. 2009).

Numerous studies identify trampling as a human impact on Antarctic terrestrial ecosystems (e.g., Chen & Blume 1997; Kriwoken & Roots 2000), but quantitative studies (e.g., Tejedo et al. 2009) are still scarce. The consequences of pedestrian traffic vary according to the nature of the soils and vegetation being considered. In terms of soil structure and surface properties, trampling produces an increase in track width, penetration resistance and bulk density (Campbell et al. 1998; Tejedo et al. 2005; Tejedo et al. 2009), micro-relief changes and visual impacts (Campbell et al. 1998; O'Neill et al. 2010), albedo alterations (Campbell et al. 1994), and modifications in nutrient cycles including reduced soil CO_2 flux in some cases (Ayres et al. 2008). Several impacts on soil biota have also been identified, the most obvious being reduction in vegetation cover and loss of vegetal biomass around paths (de Leeuw 1994; Pertierra et al. 2013). Ayres et al. (2008) observed reductions of up to 52 and 76%, respectively, in densities of two species of nematode, *Scottnema lindsayae* and *Eudorylaimus* sp., between paths with heavy pedestrian traffic and nearby undisturbed reference areas. Tejedo et al. (2009) detected a clear decrease in Collembola abundance with increased pedestrian traffic, and Greenslade et al. (2012) similarly noted large reductions in soil collembolan densities in areas on Deception Island subject to a high level of visitation relative to neighbouring undisturbed areas. Finally, some authors have proposed the possibility of non-indigenous species establishment as a direct result of the foot traffic associated with human presence, although there is still little evidence about the relative importance of this mechanism (Frenot et al. 2005). Given this background, protection of Antarctic soil ecosystems is a priority, as it provides habitat for fauna and flora which are regionally important and, in some cases, include endemic representatives.

The political context of Antarctic governance provides an important framework in efforts to develop mechanisms to protect soils in this region. Hughes & Convey (2010) highlight that Antarctica is unique in being "governed" through an international treaty, which currently has 50 signatory nations. This agreement, the Antarctic Treaty, places existing national territorial claims in abeyance, allows unrestricted movement cross the continent, and specifies that signatory nations should have a peaceful, scientific presence in the region. The Protocol on Environmental Protection to the Antarctic Treaty, also known as the Madrid Protocol, which came into force in 1998, provides the main regulatory framework relating to environmental protection that is applied to all human activities involving Treaty Parties in Antarctica. Article 3.2.b.iii of the Madrid Protocol states that activities in the Antarctic Treaty area should be planned and conducted so as to avoid significant changes in the terrestrial environment. However, the Madrid Protocol does not include specific measures to minimize trampling effects. The mechanism by which the Madrid Protocol identifies risks to the environment is through the use of environmental impact assessments, which are described in Annex I and should be applied to all activities undertaken in Antarctica, whether governmental, private or commercial. The Madrid Protocol also includes a series of related recommendations. Recommendation XXVIII-1, entitled "Guidance for visitors to the Antarctic," was adopted in 1994 by the Antarctic Treaty Consultative Parties and includes a series of practical and simple measures and items of advice to ensure that all visitors to Antarctica, both scientists and others, comply with the provisions of the Antarctic Treaty and the Madrid Protocol. The Secretariat of the Antarctic Treaty (SAT) has made the guidelines available in the form of "General guidelines for visitors to the Antarctic" (http://www.ats.aq/documents/recatt/att483_e.pdf). However, soils are not specifically mentioned, with explicit reference only being made to the prohibition of collecting geological items as souvenirs, including rocks and fossils. The International Association of Antarctica Tour Operators (IAATO), which includes most of the operators in this trade sector, applies a version of this recommendation as a code of conduct for their clients during their visits to Antarctica.

Apart from these general legal instruments, there are a number of specific codes of conduct developed by different organizations to ensure the proper protection and conservation of Antarctic ecosystems. The SAT has developed a collection of "Site guidelines for visitors" to provide specific instructions on the conduct of activities at the most heavily visited Antarctic sites (available at www.ats.aq/e/ats_other_siteguidelines.htm). This includes practical guidance for tour operators and guides on how they should conduct visits at those sites, taking into account the environmental values and sensitivities particular to each site. Some measures for controlling the effects of trampling are mentioned, including the demarcation of closed areas to protect vulnerable features or fragile surfaces and the establishment of walking routes to avoid vegetation trampling. The Scientific Committee on Antarctic Research (SCAR) has developed the "Environmental code of conduct for terrestrial scientific field research in Antarctica" (SCAR 2009), a document approved at the 30th SCAR Delegates Meeting in 2008 and by the Council of Managers of National Antarctic Programs. This code of conduct provides recommendations on the undertaking of scientific field activities while protecting the Antarctic environment for future generations, complementing the relevant sections of the Madrid Protocol and providing guidance for all researchers conducting scientific research on land, lakes and ice. Although non-binding, all countries with permanent and summer scientific stations are encouraged to include this code of conduct within their operational procedures. These guidelines are underlain by the precautionary principle and based on the field experience of members of relevant organizations. With reference to trampling through pedestrian traffic, two measures are proposed: (1) to stay on established trails when available, and (2) to avoid walking on areas that are especially vulnerable to disturbance. However, importantly, as yet few field data are available to provide robust and objective support for these measures.

This article evaluates the recommendations relating to path use proposed in various codes of conduct. Paths have become established in many Antarctic locations, usually in an *ad hoc* fashion, to access certain areas including tourist sites, coastal vertebrate colonies, water supplies, warehouses and research sites. Around research stations in particular, SCAR's "Environmental code of conduct for terrestrial scientific field research in Antarctica" recommends that people follow marked routes. These permanent facilities often occupy large areas that are effectively "sacrificial areas" due to the high level of use that they are exposed to. However, it is not clear that current recommendations are appropriate in the case of paths located in the vicinity of temporary field camps, or in sampling areas or tourist visitation sites which are subjected to more limited use. To address this issue, we carried out a range of experimental trampling studies in several locations of the maritime Antarctic remote from the influence of research stations. Additionally, we analysed the physical recovery capacity of soil to assess the time required for recovery of impacted surfaces. Our data contribute to improving management strategies for this type of human impact.

Methods

Study areas

This research was conducted in three Antarctic locations, all situated in the South Shetland Islands: Byers Peninsula, Livingston Island (62°34′S, 61°13′W); Barrientos Island (62°24′S, 59°47′W); and Whalers Bay, Deception Island (62°59′S, 60°34′W) (Fig. 1). Some basic soil characteristics for the study sites are summarized in Table 1. Byers Peninsula comprises an area of about 60 km^2 at the western end of Livingston Island. Most of this peninsula remains snow-free during the austral summer. Including over 110 lakes and ponds as well as numerous seasonal streams, this important site hosts one of the most complex and diverse limnetic systems in the maritime Antarctic (Toro et al. 2007). Terrestrial biodiversity is also relatively high (Richard et al. 1994; Sancho et al. 1999). The annual average temperature ranges from -1.5 to -3°C (Toro et al. 2007). Precipitation is high, about 700–1000 mm per year, occurring mostly as rain in summer (Bañón 2001). In 2002, Byers Peninsula was designated as Antarctic Special Protected

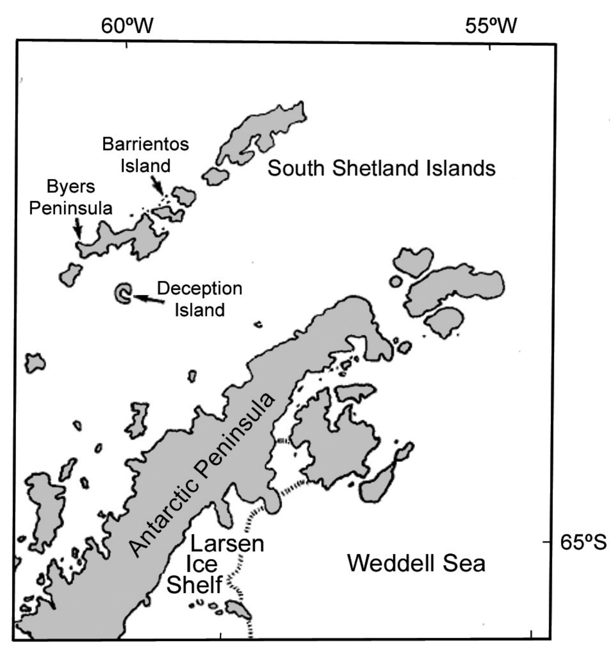

Fig. 1 Map showing the northern Antarctic Peninsula and offshore islands. The locations of Byers Peninsula, Barrientos Island and Deception Island are indicated.

Table 1 Some chemical characteristics of the soils present in the study areas.

Location	Site description	pH	Organic matter (%)	Electrical conductivity (dS/m)	Carbon: nitrogen ratio	Carbon (%)	Nitrogen (%)	Texture
Byers Peninsula[a]	Soil with patches of cushion-forming mosses and lichen	6.1	1.6	0.07	12.2	1.84	0.15	Sandy
Barrientos Island[b]	Bare ground caused by a tourist path crossing a moss meadow	5.6	3.1	0.04	7.2	2.15	0.30	Loamy
Whalers Bay[b]	Low fluvial terraces close to the beach	7.5	0.2	0.04	2.7	0.11	0.04	Very coarse sandy soil

[a]Data from Pertierra et al. (2013).
[b]Data from Samsundar (2011).

Area No. 126, although it has come under different protection regimes since 1966. Human presence has therefore been limited in recent years to scientific activity, with most researchers occupying temporary camps in the vicinity of South Beaches. Most other parts of the peninsula have remained free from regular human influence, providing an excellent opportunity to develop experimental studies on almost pristine soils.

Barrientos Island is situated at the north entrance to English Strait, between Robert and Greenwich islands. It is relatively small, only 1.5 km wide at most. The island's north coast comprises cliffs that reach a height of 70 m, sloping gently towards the south coast. Although there are no site-specific data, the climate is assumed to be closely similar to neighbouring Greenwich Island, which hosts the Ecuadorian Pedro Vicente Maldonado Station. The average temperature during the austral summer at the latter station ranges between -2 and $+2$°C, with about 600 mm of rainfall per year. Barrientos Island is a popular tourist destination, usually amongst the top 20 Antarctic visitor sites (IAATO 2011), and has received around 6300 visitors per season in the last five years. Most tourist visits concentrate on coastal wildlife colonies, with roughly 11% of visitors exploring the whole island (IAATO 2011). Amongst its main attractions for visitors is the presence of very extensive moss carpets, numerous lichens, geomorphological features, and breeding colonies of seabirds and mammals. These features and its popularity led to its inclusion in the first set of "Site guidelines for visitors" developed by the SAT. Relating to the movement of visitors around this island and their effects on soils and associated communities, these guidelines recommend: (1) that visitors avoid walking on any vegetation, and (2) that visitors respect the island's proposed zoning (Fig. 2), which establishes two free-roaming areas at the western and eastern ends of the island where they can walk and explore under supervision. The guide includes several closed areas created to protect the extensive moss carpets located in the central part of the island, the main breeding sites used by southern giant petrels (*Macronectes giganteus*) and one area used to monitor chinstrap penguins (*Pygoscelis antarcticus*). Connecting the two free-roaming areas is a path which runs over the rocks along the shoreline at the island's eastern end and along a narrow gravel stream bed through the vegetation. This path is further specified for use by closely guided groups of no more than 10 visitors. Only one group should follow the stream bed at a time, taking extreme care not to trample the edges of the vegetation (SAT 2006).

Receiving an average of 15 300 visitors per season in the last five years, Whalers Bay is the most popular visitor site on Deception Island, and one of the most visited sites in the Antarctic (Lynch et al. 2010; IAATO 2011). It includes a small harbour where the remains of the abandoned British "Base B" and the Norwegian Hektor Whaling Station can be visited. The latter is the most significant whaling remains in the Antarctic. The location also includes various geological features of volcanic origin (Smellie 2002), including a lahar (mud slide) which formed as a result of an eruption in 1969 that caused the

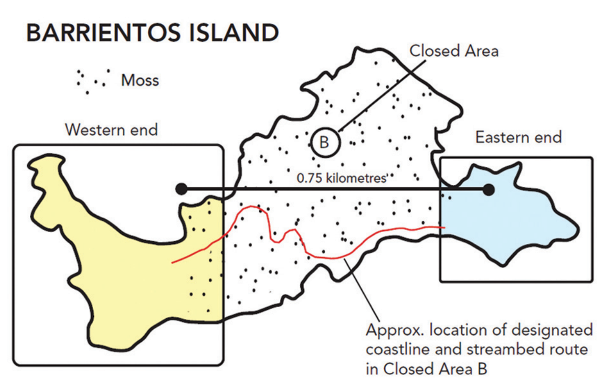

Fig. 2 Schematic diagram of the zoning of Barrientos Island. There are two free-roaming areas in both ends of the island. A designated route crosses Closed Area B, which occupies the central part of the island. Source: Secretariat of the Antarctic Treaty (SAT 2006).

abandonment of the British and Chilean stations on the island. The climate of Deception Island is again maritime polar, with an annual average temperature of $-3°C$ and about 500 mm of precipitation per year. Deception Island was adopted as an Antarctic Specially Managed Area at the 28th Antarctic Treaty Consultative Meeting in 2005. The Deception Island management package (Deception Island Management Group 2005) contains a "Code of conduct for visitors to Deception Island", which was used as the basis to develop the various island's visitor site guides. Currently, there are site guidelines for the four more visited locations on Deception Island: Whalers Bay, Baily Head, Telefon Bay and Pendulum Cove. These guidelines are similar to those proposed for Barrientos Island, including the designation of free-roaming and closed areas. Several sites of current geothermal activity and with exceptional associated vegetation communities collectively form Antarctic Specially Protected Area No. 140.

Physical and biological impacts on established paths

In our analyses of trampling impacts, only the first 10 cm of the soil profile was considered as this is the layer most likely to be disturbed by pedestrian traffic (LaPage 1967). The two parameters used for monitoring trampling effects were soil penetration resistance (a proxy for soil compaction) and springtail abundance. Both are closely related to important ground surface properties, including soil texture, porosity, organic matter content, aeration and infiltration rate (Soil Survey Staff 2006). Because both parameters are strongly influenced by soil water content, experiments were only carried out when the circumstances were appropriate, i.e., when the ground surface was well drained. Together, these data provide the first robust quantification of the consequences of concentrated human movement along established trails in terms of physical and biological changes. The value of these parameters in assessing human impact has been confirmed by several studies, as summarized by Tejedo and co-authors (Tejedo et al. 2005; Tejedo et al. 2009).

Penetration resistance was obtained using a manual precision penetrometer ST-308 (Eurosite, Ancona, Italy). This instrument records the force (kg/cm^2) necessary to introduce a marker into the ground to a certain depth. The instrument's measuring range was 0 to 6 kg/cm^2. When the upper measurement limit was exceeded, an arbitrary value of 7 kg/cm^2 was assigned for graphical representations and calculations. Springtails were obtained from samples of approximately 500 cm^3 taken from the top 0–10 cm of the soil profile. These samples were collected using a plastic cylinder of known volume. Each core was broken up by hand onto a wire mesh of (1 mm mesh) and was exposed for 48 h to a 40 W light placed 20 cm above the sample, following the method used by Convey et al. (1996). To avoid drying out, active arthropods migrate to the lower layers of the sample and fall through the mesh. Specimens pass through a funnel into a jar containing 80% ethanol. Preserved springtails were returned to Spain, where they were counted and identified to species level by optical microscopy.

Studies were conducted along: (1) an experimental length of path specifically created in a previously undisturbed area on Byers Peninsula; (2) part of the trail net created by scientists since the 2001–02 summer season in the vicinity of the temporary camp located at South Beaches, Byers Peninsula; and (3) lengths of different tourist paths on Barrientos Island and at Whalers Bay that experience intensive use by Antarctic standards. All protocols were based on well-established methods typically used in recreation ecology and applied in the analysis of soil disturbance and trampling consequences (e.g., Marion & Leung 2001; Farrell & Marion 2002; Cole 2004; Marion & Olive 2006; Marion et al. 2006; and references therein).

The Byers Peninsula experimental path length was created in the 2003–04 season in a flat, pristine area. In January, after the melting of winter snow, four transects of 2 m length and 60 cm width were created. Each one was subjected over a single day to a different use level: 0 (control), 100, 300 and 600 pedestrian transits by a researcher weighing about 88 kg. Soil penetration resistance was recorded at three points for each trampling intensity, and with five replicate measurements taken at each point. Three cores were taken to determine the abundance of springtails under each experimental level of pedestrian traffic.

During the same field season, soil penetration resistance and springtail abundance were recorded on three paths used by researchers in the area of the temporary camp located at South Beaches. Here, two sampling areas were established: the centre of the path (considered the most impacted area); and a strip 3 m away from the path (used as control area). In each area, three points separated by 1 m were selected as sampling points. Again, five replicates per point were obtained for penetration resistance, with a single core for the extraction of Collembola obtained at each point.

For analyses on Barrientos Island, a stretch of 225 m on an unofficial trail was selected. The route proposed in the island's "Visitor site guide" was not used for this purpose as it runs mostly over rocks and a stream bed, limiting the possibility of applying the selected parameters.

After an initial visual inspection used to measure the length of this studied path, soil penetration resistance was measured every 5 m, both in the centre of the path (zone of maximum impact) and 50 cm to either side (used as control areas). We recorded 138 points, 46 per zone, taking five replicates per point. Most of the measurements in the outer control areas actually lay within the path boundary, which was over 100 cm wide (about two-thirds of all data collected). This sampling regime was considered the best option because the path crosses the extensive moss carpets located in the central part of the island, and most of the substratum outside the path boundary was not comparable to that located within it. The maximum slope and path width were also recorded every 5 m, using a hypsometer (Suunto, Vantaa, Finland) and a measuring tape. Cores for the extraction of springtails were taken every 40 m, in the centre of the path and 50 cm on either side, totalling 18 samples.

Two complementary studies were developed on Barrientos Island and Deception Island to assess the influence of slope and soil surface texture on soil penetration resistance. On Barrientos Island, a sloping stretch of 30 m was selected from the officially recommended path that runs over a loamy soil (Samsundar 2011). Soil penetration resistance was recorded at the centre of the path every metre, with five replicates per point.

On Deception Island, the 700 m trail to Neptune's Window was chosen to be compared with the 225 m stretch of tourist path analysed (described above) on Barrientos Island. The width, slope and penetration resistance (five replicates) were recorded every 10 m along this trail, also using a control area defined 50 cm from the centre of the path. This path runs over very coarse volcanic sand soil.

Physical resilience

To quantify the physical resilience of Antarctic soils, three experiments were conducted. The first was undertaken on Byers Peninsula and involved medium-term (three years) research on an experimental path in which the changes in the soil penetration resistance were analysed over time. In the 2006–07 summer season, five stretches of 2 m length were demarcated in a vegetation-free soil in order to expose them to a known number of pedestrian transits by a researcher weighing ca. 100 kg: 0 (not used), 250, 500, 1000 and 2000 transits. This experiment was carried out one day after snow retreat from the demarcated areas. Soil penetration resistance was measured for each use level (five replicates) in this season and again in the 2009–10 summer.

The most impacted stretch from the paths created by scientists at South Beaches, Byers Peninsula, was selected for use in a further experiment of five years' duration. In 2002–03, soil penetration resistance was measured at 0 and 3 m from the centre of the path (most impacted area and control zone, respectively). At each distance, three points separated by 1 m were measured. The data collection was repeated in the 2007–08 season, when five replicates per point were undertaken. From 2002–03 to 2005–06, the path experienced normal use, while it was closed during 2006–07 and 2007–08 to test the recovery of the ground surface.

Finally, the recovery capacity of tourist paths was evaluated on Barrientos Island. Most of this path was covered by snow and ice when it was visited in 2010–11 season, and we therefore assumed that soils remained basically unaltered from the previous tourist season. In the available ice-free stretch (110 m), penetration resistance data were taken every 10 m both in the centre of the path and 50 cm to either side to compare them with those obtained in 2008–09 season. Thirty-three points were recorded, 11 per zone, with five replicates per point.

Statistics

The Mann-Whitney non-parametric test was applied to compare groups. The median of the five recorded replicates of penetration resistance at each sampling location was used for statistical analyses as this measure of central tendency is more robust than the arithmetic mean and is less affected by the extreme values that are frequently encountered in soils because of natural heterogeneity at the micro-scale.

Results

The data obtained on Byers Peninsula in the 2002–03 summer season allowed the construction of impact-response curves for the two monitored parameters. These data, which are included in Tejedo et al. (2009), show how the impact developed with increasing trampling pressure. There was a clear increase in penetration resistance with increasing pedestrian transits. Before the impact, the penetration resistance was around 1 kg/cm^2 on average, whereas it was close to 5 kg/cm^2 after 600 transits. Our results fit well to a linear model ($y = 0.0068x + 0.9747$, $r^2 = 0.7948$, $P < 0.001$), although a polynomial equation explains a slightly higher proportion of the variability, up to 83% ($y = 0.000009x^2 + 0.0125x + 0.6136$, $r^2 = 0.8364$, $P < 0.001$). Data corresponding to 300 pedestrian transits showed some variability, which could be due to differences at the

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micro-relief level. The data suggest that even a low use level, around 100 pedestrian transits, significantly increased soil penetration resistance (Mann-Whitney test, $P = 0.050$).

In the study developed for the second monitored parameter, two collembolan species were sampled: *Cryptopygus antarcticus* and *Friesea woychiechowskii*. The majority of springtail specimens obtained were *C. antarcticus* (90.6%) and, as a result, the data indicated that only *C. antarcticus* was significantly affected by the trampling impact. In the non-impacted zone, 180 *C. antarcticus* individuals were obtained in total (including the three replicates), 106 in the stretch subjected to 100 pedestrian transits, 44 in the stretch subjected to 300 footsteps, and 16 at the maximum level of trampling (600 transits). *F. woychiechowskii* did not show the same trend, yielding a total of 9, 6, 8 and 13 individuals, respectively, in each stretch. Springtails did not disappear completely even at the highest trampling level applied, although their number was reduced markedly (by 84.7%, relative to the initial value). The most abrupt change in their abundance occurred at 300 pedestrian transits. The data are not fitted well by any simple mathematical model, although a reduction in collembolan abundance is observed when use increases ($y = 0.0002x^2 - 0.2198x + 60.879$, $r^2 = 0.3876$).

Soil penetration resistance was measured across a network of paths which were created by the researchers on Byers Peninsula and in a tourist path on Barrientos Island (Fig. 3a). In both cases, there were higher levels of compaction in the centre of the track than in control areas (Mann-Whitney test, $P < 0.001$ for both paths). Physical degradation of the tourist route surface on Barrientos Island was significantly higher (Mann-Whitney test, $P = 0.003$); in many cases the upper limit of detection of the penetrometer was exceeded. Total abundances of Collembola (Fig. 3b) were also significantly different between the most impacted zones and control areas in both cases (Mann-Whitney test, $P < 0.001$ in each case). On the Barrientos Island path, only 29 specimens were found in all samples ($n = 6$) from the centre of the path, while a total of 822 individual springtails (all *C. antarcticus*) were obtained in the 12 samples from control areas.

The influence on the penetration resistance of some key physical characteristics of soils affected by trampling is illustrated in Figure 4. The slope (Fig. 4a) has a clear influence on resistance, with the section of path crossing a gradient ($17.6 \pm 0.34°$) showing values significantly greater than the near-horizontal section ($4.87 \pm 0.61°$; Mann-Whitney test, $P < 0.001$). Most of the values obtained from the former exceeded the upper detection limit of the penetrometer, whereas data variability was much greater for the latter. Regarding the dominant texture of the ground surface (Fig. 4b), soil penetration resistance in the loam soil was significantly higher than in the very coarse sand soil, both in the centre of the track (with an average of 5.25 vs. 1.48) and in the control area (0.71 vs. 0.05; Mann-Whitney test, $P < 0.001$). Clear differences were also observed in the data variability, being much higher for the trail on the Barrientos Island. The variance for the centre of the path with a loamy texture (Barrientos Island) was 1.21, while this figure was 0.18 for the path with a very coarse sand texture (Deception Island). A similar trend was observed in the control areas, with variances of 0.71 and 0.05, respectively.

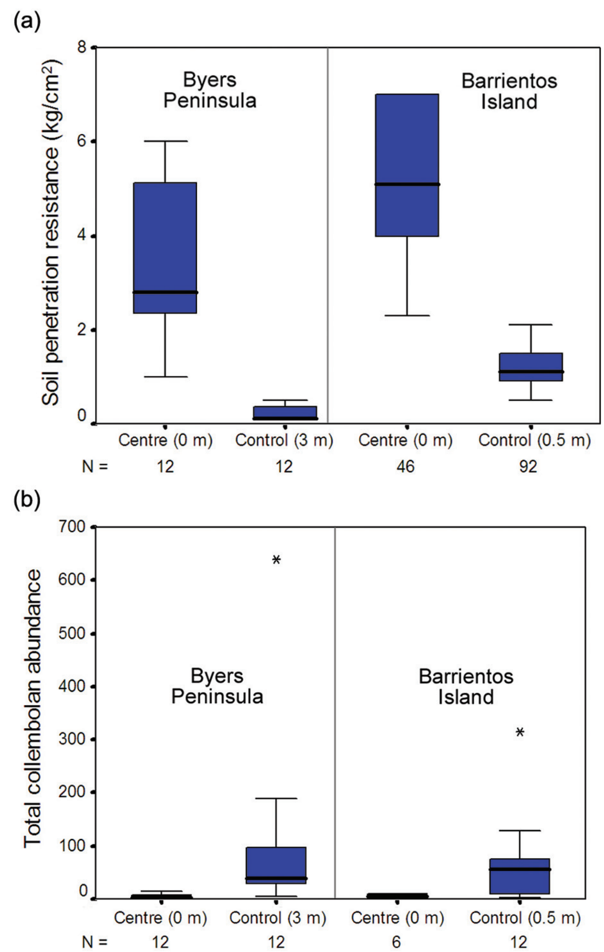

Fig. 3 (a) Soil penetration resistance and (b) total collembolan abundance were measured in Byers Peninsula in a group of trails created by scientists during their fieldwork and in a tourist trail located on Barrientos Island. In both cases, data were obtained in the most impacted zone (centre of the track) and in nearby areas used as control. In the box plots, the asterisks represent outliers.

The physical recovery capacity in the medium-term (two–three years) for maritime Antarctic soils is illustrated in Fig. 5. In all cases, there was an improvement over time in the properties of the soil surface layer. In the experimental path created in 2006–07 and revisited three years later, all the penetrometer values obtained in the latter season were very similar, around 1 kg/cm^2. In contrast, at heavily trampled areas (subjected to 2000 pedestrian transits), initial values reached 6 kg/cm^2. The penetration resistance in the control area was greater in 2009–10 than in the 2006–07 season (Fig. 5a). The path located in the research camp in Byers Peninsula showed a similar trend (see Fig. 6 in Tejedo et al. 2009). The centre of this track presented initially extreme values of penetration resistance, which substantially decreased after it had been closed for two years (Mann-Whitney test, $P = 0.037$). Finally, on Barrientos Island (Fig. 5b), the local environmental conditions suggested that the path had been little used in the 2010–11 season, providing an analogy to a recovery situation. Data obtained here reinforce this suggestion, with a lower resistance being obtained for the 2010–11 season both in the centre of the path and in the control areas (Mann-Whitney test, $P < 0.001$ in each case). In the most

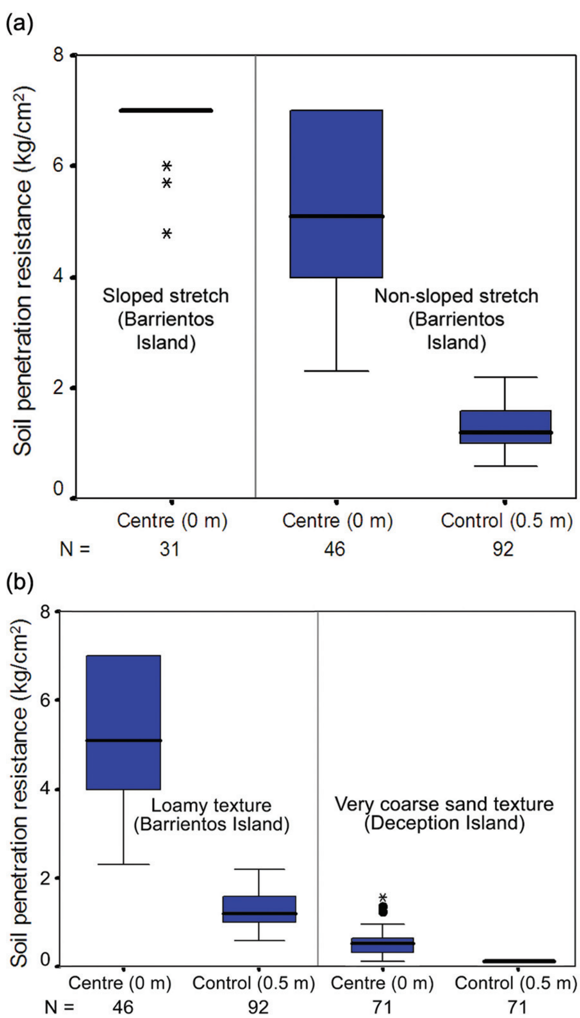

Fig. 4 Influence on the soil penetration resistance of the slope and the dominant texture of the ground surface. (a) This parameter was analysed in two stretches with different slopes from the network of tourist paths on Barrientos Island. The first presents a steep average slope while the other has a flat profile. (b) The flat stretch, which has a loamy texture, is compared with the tourist path leading to Neptune's Window, Deception Island. This trail is dominated by lapilli. The dots represent extreme data and the asterisks are outliers.

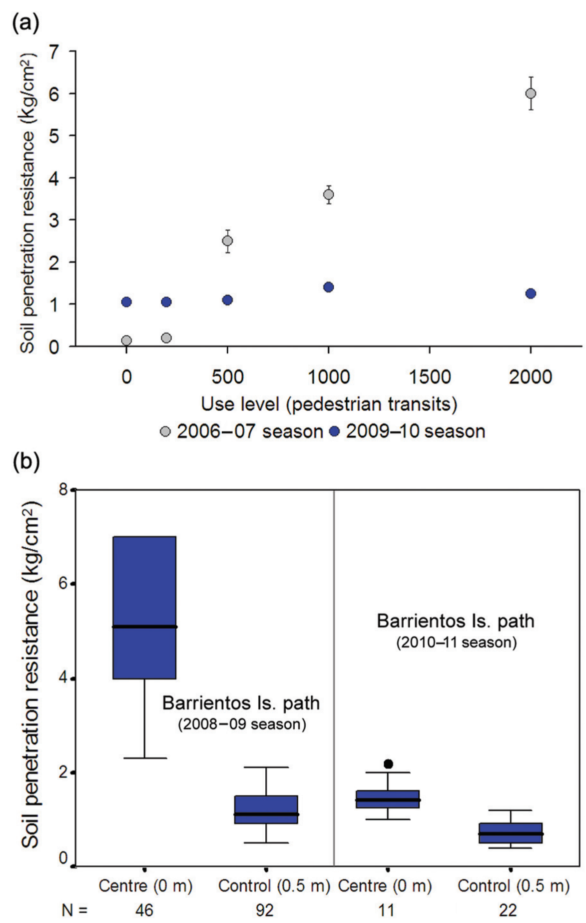

Fig. 5 Study of the ground surface physical recovery capacity using the soil penetration resistance. (a) An experimental stretch on Byers Peninsula was subjected to different trampling intensities in the 2006–07 season. Data were recorded again three years later. (b) Data from a non-official tourist path on Barrientos Island in two non-consecutive years. The left part of (b) shows data for the 2008–09 season along a 225 m stretch. On the right, data are shown for the 2010–11 season from a partial section of the previous stretch. Data were taken at the centre of the path and 50 cm on each side of this point (control areas). In the box plots, dots represent extreme data.

Fig. 6 Waterlogged area on the designated track route on Barrientos Island. Pedestrians trying to avoid the mud widen the track.

impacted area, the penetration resistance decreased from an average of around 5 kg/cm^2 to 1.43 kg/cm^2.

Discussion

The relationship between trampling and physical and biological disturbance to maritime Antarctic soils has been partially analysed by Tejedo and co-authors (Tejedo et al. 2005; Tejedo et al. 2009), focussing on a limited set of experimental paths and trails created by scientists in the vicinity of a temporary camp on Byers Peninsula. In the present article, we compare the previous results with those obtained from tourist trails located on Barrientos Island and Deception Island in order to evaluate whether they can be generalized to soils subjected to a higher level of use. Our data indicate that maritime Antarctic soils can be altered by relatively low trampling intensity. The threshold at which very obvious damage occurred in an experimental path was very low, around 100–300 foot passes, depending on the parameter considered. As the intensity of trampling increased, compaction and total collembolan abundance were reduced. Our data suggest that human trampling pressure can generate an immediate impact on the abundance of soil fauna. This may be due to direct killing of specimens, to changes in the microhabitat that reduce the ecological viability of the Collembola, or a combination of both processes. Trampling alters the macroporosity and the structure of the upper few centimetres of the ground surface, reducing the water-holding capacity, permeability and water infiltration (Cole 2004). Abiotic features of Antarctic terrestrial habitats, particularly limited availability of liquid water, strongly influence collembolan abundance (Convey et al. 2003; Hayward et al. 2004). Therefore, significant changes in soil properties as a result of trampling above a certain threshold could reduce the viability of these organisms.

Impacts observed at the centre of paths are clearly higher than those recorded in adjacent control areas. This suggests that implementing a strategy of impact concentration through path creation may not be the most appropriate option in all cases. Rather than path creation, in areas subjected to very limited use a better strategy might be to define access corridors within which movement could be more dispersed without following a specific route. However, in areas subjected to higher use levels the concentration strategy would remain as the best option. Path creation also has benefits that can be important factors in cases where the use intensity is not the only variable to consider. For example, it could facilitate the monitoring of certain impacts by reducing the area under control measures, for instance, in detecting the presence of non-indigenous species. The concentration strategy allows the designation of routes which take into account the breeding activity of species sensitive to human presence and the safety of hikers, for instance, avoiding dangerous areas near cliffs. Partially as a result of these advantages, the use of pre-defined paths is a common recommendation in the “Site guidelines for visitors” promulgated by the SAT. But possibly the greatest advantage of these instruments is that they can permit both the concentration of impact through official paths and the dispersion of foot traffic in those areas less vulnerable to trampling, where free-roaming can be permitted. This mixed strategy has given so far good results in certain heavily visited tourist sites, such as Barrientos Island and Whalers Bay, and more generally is a strategy widely used in recreation ecology.

The international Leave No Trace programme, which was created to assist outdoor enthusiasts in reducing their impacts on the environment, proposes different strategies for camping and hiking, depending on whether visiting popular areas or pristine zones (Harmon 1997; www.LNT.org). The implementation of codes of conduct directly supported by scientific knowledge and activity zoning will normally be a less harmful alternative to manage the movement of scientists and tourists than other more intrusive measures, including the installation of permanent hiking facilities such as boardwalks or causeways. While such constructions may be appropriate in the immediate vicinity of research stations and have also been proposed for some specific high use intensity sub-Antarctic locations (McKee 2006), the Antarctic Treaty System community generally discourages their use at visitor sites because they can severely affect the aesthetic values of Antarctica (Bastmeijer 2007;

Tin et al. 2008), as well has having more local impacts such as obstructing faunal movement. It would be advantageous to include professional trail designers in processes selecting those routes that are more sustainable, such as alignments that seek to remain on rock or coarse substrates, avoid animal trails, respect vegetation, and to avoid steep gradients vulnerable to erosion or muddy soils that encourage trail widening.

Among the characteristics of soils affected by trampling that influence the degree of degradation, the most important factors appear to be slope, the dominant texture of the ground surface, and the presence of muddy areas. Our data suggest that steeper slopes can increase the compaction of soil caused by trampling, as reported in other environments (Leung & Marion 1996; Whinam & Chilcott 2003). Paths formed on a steep relief are more vulnerable to concentration of trampling than those running over a flatter terrain. For trails that cross steep-sloped sites it would be desirable to define a single track to keep the disturbed area to a minimum, following stony or bouldery surfaces wherever possible, and using aligned trails that transit slopes at an angle (e.g., 45 degrees from the fall line). Regarding the dominant texture of the ground surface, Campbell et al. (1998) concluded that soils dominated by large particles were less vulnerable to compaction, a finding consistent with our data obtained from Deception Island. In this island's environment, where soils are dominated by volcanic lapilli, a volcanic material ranging in size from 2 to 64 mm in diameter, foot traffic along defined fixed paths often causes permanent changes in ground surface colour and texture. Such alterations may be reduced or even avoided by dispersing the routes taken by pedestrians. The final factor, the presence of muddy areas, was highlighted by Gremmen et al. (2003), who observed that paths created in waterlogged areas often experienced flooding. This resulted in expansion of the track boundary and zone of disturbance as pedestrians tried to avoid the worst affected areas. Similar track expansion was observed during our research on Barrientos Island (Fig. 6). Where such increased degradation occurs, changes need to be made in path route designation.

As well as confirming the vulnerability of maritime Antarctic soils to trampling, the documentation of their recovery capacity is also important. The generally accepted assumption is that disturbance effects on Antarctic soils are very long-lasting, especially in continental environments such as the Victoria Land Dry Valleys and Transantarctic Mountains (Campbell & Claridge 1987; Ayres et al. 2008; Hodgson et al. 2010). However, our data suggest that some areas of maritime Antarctic soil that have suffered intermediate levels of use could possibly physically recover after a period of as little as two–three years without human presence. Separately, a three–five-year interval of time has been suggested for bryophyte and associated invertebrate communities to develop on previously bare soil (Convey 2003), although soil exposed for longer probably needs more time to reach a complete recovery of soil communities, and signs of damage (e.g., footprints, vehicle tracks) can remain visible in moss turf vegetation for many decades. The repeated freeze–thaw cycling typically experienced in many maritime Antarctic soils could assist recovery from soil surface layer impacts in a relatively short period of time. However, for those walking trails that support a large number of visitors each year, recovery will take longer.

Our data provide support to the proposition that the adoption of temporary closures in locations experiencing erosion, or in which vulnerable biotypes have been altered, will help their recovery. The limited use of the majority of Antarctic walking trails (below 5000 users per season according to annual IAATO statistics) would currently permit utilization of this option, which would not be appropriate in areas that receive larger numbers of visitors. Use of this management measure is not a novelty in Antarctica. Temporary closures are applied in certain breeding sites, such as Hannah Point (Livingston Island). Since the 2005–06 season, the "Visitor site guide" for this location has recommended avoiding visits between the beginning of the penguin breeding season and the end of the early phase of incubation (October to mid-January).

The current study has not investigated the effects of trampling on soil chemical variables, but data are now becoming available suggesting that trampling could reduce the amount of available nutrients in several Antarctic moss communities (Pertierra et al. 2013). A further potential impact associated with trampling is the proliferation of non-native species. Gremmen et al. (2003) highlighted that trampled areas on sub-Antarctic Marion Island (46°50′S, 37°50′E) seem to be more vulnerable to the establishment of non-native species than are vegetated undisturbed areas, and several authors consider that tracks provide routes for further human-assisted dispersal of non-native species already established on several sub-Antarctic islands (e.g., Scott & Kirkpatrick 1994; Frenot et al. 2005). However, the use of designated walking trails facilitates the identification of establishment of non-native vegetation in comparison with monitoring a network of informal (visitor-created) trails. Other key biological factors, such as soil functional gene expression and microbial community structure, were not assessed in this study and would be valuable to incorporate in future studies of this type.

It is clear that trampling can have a considerable impact on maritime Antarctic soils. However, these effects are typically localized and there are large differences in impacts between habitats (Monz et al. 2000; Gremmen et al. 2003). The existing codes of conduct have to date contributed to controlling the scale of many of the potential impacts generated by trampling. However, their recommendations require ongoing assessment and where necessary revision to ensure their continued effectiveness in the face of expected increases in the extent and intensity of human activities in future (Tin et al. 2009). In this study, we raise the possibility that the guidelines produced by the various interested or controlling organizations, such as SCAR and the SAT, could recommend different strategies depending on the local characteristics of each site, as already included in the SAT's non-binding site-specific guidelines. We suggest that some strategies proposed in SCAR's "Environmental code of conduct for terrestrial scientific field research in Antarctica" are appropriate to be applied without exception, such as the avoidance of walking in vulnerable areas. The fast degradation caused by trampling on certain vulnerable soils and plant communities has been clearly demonstrated (Campbell et al. 1993; de Leeuw 1994; Campbell et al. 1998; Gremmen et al. 2003; O'Neill et al. 2010). However, with reference to the creation and use of defined paths, consideration of different local variables may be appropriate in assessing if a strategy based on the concentration of pedestrians is the best option. Although our data indicate that the resilience and rate of recovery of maritime Antarctic soils may be higher than generally supposed, selecting the most appropriate management strategy will further help minimize physical and biological effects of trampling on the ground surface.

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References

Ayres E., Nkem J.N., Wall D.H., Adams B.J., Barret J.E., Broos E.J., Parsons A.N., Powers L.E. & Simmons B.L. 2008. Effects of human trampling on populations of soil fauna in the McMurdo Dry Valleys, Antarctica. *Conservation Biology 22*, 1544–1551.

Bañón M. 2001. *Observaciones meteorológicas en la Base Antártica Española Juan Carlos I. Monografía A-151. (Meteorological observations at the Spanish Antarctic Base Juan Carlos I. Monograph A-151.)* Madrid: National Institute of Meteorology.

Bastmeijer C.J. 2007. Special offer-7 days fly and drive Antarctica. The role of wilderness protection in deciding whether (semi)permanent tourist facilities in Antarctica should be prohibited. In A. Watson et al. (eds.): *Science and stewardship to protect and sustain wilderness values: Eighth World Wilderness Congress Symposium, September 30 – October 6, 2005, Anchorage, AK*. USDA Forest Service RMRS-P-49. Pp. 190–195. Fort Collins, CO: Rocky Mountain Research Station, Forest Service, US Department of Agriculture.

Bergstrom D.M. & Chown S.L. 1999. Life at the front: history, ecology and change on Southern Ocean islands. *Trends in Ecology and Evolution 14*, 472–476.

Campbell I.B., Balks M.R. & Claridge G.G.C. 1993. A simple visual technique for estimating the effect of fieldwork on the terrestrial environment in ice-free areas of Antarctica. *Polar Record 29*, 321–328.

Campbell I.B. & Claridge G.G.C. 1987. *Antarctica: soils, weathering processes and environment*. Elsevier: Amsterdam.

Campbell I.B., Claridge G.G.C. & Balks M.R. 1994. The effects of human activities on moisture content of soils and underlying permafrost from the McMurdo Sound region, Antarctica. *Antarctic Science 6*, 307–314.

Campbell I.B., Claridge G.G.C. & Balks M.R. 1998. Short and long-term impacts of human disturbance on snow-free surfaces in Antarctica. *Polar Record 34*, 15–24.

Cessford G. & Dingwall P.R. 1998. Research on shipborne tourism to the Ross Sea region and the New Zealand sub-Antarctic islands. *Polar Record 34*, 99–106.

Chen J. & Blume H.P. 1997. Impact of human activities on the terrestrial ecosystem of Antarctica: a review. *Polarforschung 65*, 83–92.

Cole D.N. 2004. Impacts of hiking and camping on soils and vegetation: a review. In R. Buckley (ed.): *Environmental impacts of ecotourism*. Pp. 41–60. CABI Publishing: Wallingford, UK.

Convey P. 2003. Maritime Antarctic climate change: signals from terrestrial biology. In E. Domack et al. (eds.): *Antarctic*

Peninsula climate variability: historical and palaeoenvironmental perspectives. Pp. 145–158. Washington, DC: American Geophysical Union.

Convey P. 2010. Terrestrial biodiversity in Antarctica—recent advances and future challenges. *Polar Science 4*, 135–147.

Convey P., Block W. & Peat H.J. 2003. Soil arthropods as indicators of water stress in Antarctic terrestrial habitats? *Global Change Biology 9*, 1718–1730.

Convey P., Greenslade P., Richard K.J. & Block W. 1996. The terrestrial arthropod fauna of the Byers Peninsula, Livingston Island, South Shetland Islands. *Polar Biology 16*, 257–259.

Convey P., Stevens M.I., Hodgson D.A., Smellie J.L., Hillenbrand C.-D., Barnes D.K.A., Clarke A., Pugh P.J.A., Linse K. & Cary S.C. 2009. Exploring biological constraints on the glacial history of Antarctica. *Quaternary Science Reviews 28*, 3035–3048.

Deception Island Management Group 2005. Deception Island management package. Accessed on the internet at http://www.deceptionisland.aq/package.php on 19 November 2012.

de Leeuw C. 1994. *Tourism in Antarctica and its impact on vegetation*. PhD thesis, Arctic Centre, University of Groningen.

Farrell T.A. & Marion J.L. 2002. Trail impacts and trail impact management related to ecotourism visitation at Torres del Paine National Park, Chile. *Leisure/Loisir: Journal of the Canadian Association for Leisure Studies 26*, 31–59.

Frenot Y., Chown S.L., Whinam J., Selkirk P.M., Convey P., Skotnicki M. & Bergstrom D.M. 2005. Biological invasions in the Antarctic: extent, impacts and implications. *Biological Reviews 80*, 45–72.

Greenslade P., Potapov M., Russel D. & Convey P. 2012. Global Collembola on Deception Island. *Journal of Insect Science 12*, Article 111.

Gremmen N.J.M., Smith V.R. & Van Tongeren O.F.R. 2003. Impact of trampling on the vegetation of subantarctic Marion Island. *Arctic, Antarctic, and Alpine Research 35*, 442–446.

Harmon W. 1997. *Leave no trace: minimum impact outdoor recreation*. Helena, MT: Falcon Publishing.

Hayward S.A.L., Worland M.R., Convey P. & Bale J.S. 2004. Habitat moisture availability and the local distribution of the Antarctic Collembola *Cryptopygus antarcticus* and *Friesea grisea*. *Soil Biology and Biochemistry 36*, 927–934.

Hodgson D., Convey P., Verleyen E., Vyverman W., McInnes S., Sands S., Fernández-Carazo R. & Wilmotte A. 2010. Observations on the limnology and biology of the Dufek Massif, Transantarctic Mountains 82° South. *Polar Science 4*, 197–214.

Hughes K.A. & Convey P. 2010. The protection of Antarctic terrestrial ecosystems from inter and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. *Global Environmental Change 20*, 96–112.

IAATO (International Association of Antarctica Tour Operators) 2011. Tourism statistics. Accessed on the internet at http://iaato.org/tourism-statistics on 19 November 2012.

Kriwoken L.K. & Rootes D. 2000. Tourism on ice: environmental impact assessment of Antarctic tourism. *Impact Assessment and Project Appraisal 18*, 138–150.

LaPage W.F. 1967. *Some observations on campground trampling & ground cover response*. *Research Paper NE-68*. Upper Darby, PA: Northeastern Forest Experiment Station, Forest Service, US Department of Agriculture.

Leung Y. & Marion J.L. 1996. Trail degradation as influenced by environmental factors: a state-of-the-knowledge review. *Journal of Soil and Water Conservation 51*, 130–136.

Lynch H.J., Crosbie K., Fagan W.F. & Naveen R. 2010. Spatial patterns of tour ship traffic in the Antarctic Peninsula region. *Antarctic Science 22*, 123–130.

Marion J.L. & Leung Y.-F. 2001. Trail resource impacts and an examination of alternative assessment techniques. *Journal of Park and Recreation Administration 19*, 17–37.

Marion J.L., Leung Y.-F. & Nepal S. 2006. Monitoring trail conditions: new methodological considerations. *The George Wright Forum 2*, 36–49.

Marion J.L. & Olive N. 2006. *Assessing and understanding trail degradation: results from Big South Fork National River and Recreational Area*. Laurel, MD: Patuxent Wildlife Research Center, US Geological Survey.

McKee R. 2006. South Georgia Government Update 2006. Paper presented at the 17th Annual General IAATO Meeting, 24–30 April, Washington DC.

Monz C.A., Pokorny T., Freilich J., Kehoe S. & Ayers-Baumeister D. 2000. The consequences of trampling disturbance in two vegetation types at the Wyoming Nature Conservancy's Sweetwater River Project area. In D.N. Cole et al. (eds.): *Wilderness Science in a Time of Change Conference. Vol. 5. Wilderness ecosystems, threats, and management. USDA Forest Service RMRS-P-15.* Ogden, UT: Rocky Mountain Research Station, Forest Service, US Department of Agriculture.

O'Neill T.A., Balks M.R. & López-Martínez J. 2010. A provisional method for assessing the impact on, and recovery of, Antarctic desert pavements from human-induced disturbances. In R.J. Gilkes & N. Prakongkep (eds.): *Proceedings of the 19th World Congress of Soil Science: soil solutions for a changing world.* Brisbane, Australia, 1–6 August 2010. Published on DVD. International Union of Soil Sciences.

Pertierra L., Lara F., Tejedo P., Quesada A. & Benayas J. 2013. Rapid denudation processes in criptogamic communities from Maritime Antarctica subjected to human trampling. *Antarctic Science 25*, doi: 10.1017/S095410201200082X.

Richard K.J., Convey P. & Block W. 1994. The terrestrial arthropod fauna of the Byers Peninsula, Livingston Island, South Shetland Islands. *Polar Biology 14*, 371–379.

Samsundar J. 2011. *Análisis de la diversidad microbiana y su relación con las características físico–químicas en suelos del archipiélago Shetland del Sur (Antártida) con un diferente impacto antrópico. (Analysis of microbial diversity and its relationship with the physical–chemical characteristics of soils in the South Shetland Islands [Antarctica] with different levels of human impact.)* Master's thesis, Faculty of Biology, Universitat de València.

Sancho L.G., Schulz F., Schroeter B. & Kappen L. 1999. Bryophyte and lichen flora of South Bay (Livingston Island, South Shetland Islands, Antarctica). *Nova Hedwigia 68*, 301–337.

SAT (Secretariat of the Antarctic Treaty) 2006. Barrientos Island (Aitcho Islands). Visitor site guide. Accessed on the internet at http://www.ats.aq/siteguidelines/documents/Barrientos_e.pdf on 19 November 2012.

SCAR (Scientific Committee on Antarctic Research) 2009. Environmental code of conduct for terrestrial scientific field research in Antarctica. Accessed on the internet at http://www.scar.org/researchgroups/lifescience/Code_of_Conduct_Jan09.pdf on 19 November 2012.

Scott J.J. & Kirkpatrick J.B. 1994. Effects of human trampling on the sub-Antarctic vegetation of Macquarie Island. *Polar Record 30*, 207–220.

Smellie J.L. 2002. The 1969 subglacial eruption on Deception Island (Antarctica): events and processes during an eruption beneath a thin glacier and implications for volcanic hazards. *Geological Society Special Publications 202*, 59–79.

Soil Survey Staff 2006. *Keys to soil taxonomy.* 10th edn. Washington, DC: Natural Resources Conservation Service, US Department of Agriculture.

Stewart E., Draper D. & Johnston M. 2005. A review of tourism research in the polar regions. *Arctic 58*, 383–394.

Tejedo P., Justel A., Benayas J., Rico E., Convey P. & Quesada A. 2009. Soil trampling in an Antarctic Specially Protected Area: tools to assess levels of human impact. *Antarctic Science 21*, 229–236.

Tejedo P., Justel A., Rico E., Benayas J. & Quesada A. 2005. Measuring impacts on soils by human activity in an Antarctic Special Protected Area. *Terra Antarctica Reports 12*, 57–62.

Thomas D.N., Fogg G.E., Convey P., Fritsen C.H., Gili J.M, Gradinger R., Laybourn-Parry J., Reid K. & Walton D.W.H. 2008. *The biology of polar regions* 2nd edn. Oxford: Oxford University Press.

Tin T., Fleming Z.L., Hughes K.A., Ainley D.G., Convey P., Moreno C.A., Pfeiffer S., Scott J. & Snape I. 2009. Impacts of local human activities on the Antarctic environment. *Antarctic Science 21*, 3–33.

Tin T., Hemmings A.D. & Roura R. 2008. Pressures on the wilderness values of the Antarctic Continent. *International Journal of Wilderness 14*, 7–12.

Toro M., Camacho A., Rochera C., Rico E., Bañón M., Fernández-Valiente E., Marco E., Justel A., Avendaño M.C., Ariosa Y., Vincent W.F. & Quesada A. 2007. Limnological characteristics of the freshwater ecosystems of Byers Peninsula, Livingston Island, in maritime Antarctica. *Polar Biology 30*, 635–649.

Whinam J. & Chilcott N. 2003. Impacts after four years of experimental trampling on alpine/subalpine environments in western Tasmania. *Journal of Environmental Management 67*, 339–351.

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El posible impacto humano en isla Decepción

El posible impacto humano en isla Decepción

Isla Decepción es un volcan emergido donde su actividad reciente ha creado un medio singular de excepcional atractivo turistico e interes cientifico.

Este documento informativo plantea una relación de hechos observados que sugieren la compleja variabilidad de los problemas de conservación que la Isla mantiene, ante el considerable numero de visitantes que, por su singularidad, se concentran en determinadas zonas de la Isla.durante los veranos antarticos.

1- Las areas de visita en la isla

Cuatro áreas en *Decepción* acumulan una cifra notable de visitas desde que la IAATO registra sistemáticamente la actividad turística en la Antártida. Es interesante señalar que mientras las visitas *a Bahía Balleneros* (13.966 visitantes en la campaña 2008/2009) presentan una tendencia de crecimiento positivo, las cifras de *Bahía Telefono* (3.496 visitantes), ***Pendulo*** (2.802 visitantes en 2008/2009) y ***Baily Head*** (2.764 vistantes en 2008/2009) fluctúan en los últimos años, llegando incluso a reducirse.

En ***Bahía Balleneros*** la mayoría de los turistas se concentran en la zona de la playa, por lo que la propia dinámica intermareal se ocupa de ir borrando periódicamente sus huellas. En la zona de acceso a *la* ***Ventana de Neptuno*** se pueden apreciar varios senderos bien marcados como consecuencia del tránsito de los visitantes observándose varios senderos secundarios que conviven con el trazado principal, por lo que, para evitar que se creen nuevas rutas alternativas, sería conveniente balizar el recorrido.

En ***Caleta Péndulo*** las fuentes termales en la costa a escasa profundidad ofrecen a los visitantes la oportunidad de “bañarse” en aguas cálidas. La IAATO ha acordado que sus socios desde hace un par de campañas no participen en hacer las pozas para que se bañen los turistas. Este puede ser el motivo que explique la reducción progresiva del número de turistas que acceden a este punto.

Bahía Teléfono es utilizado frecuentemente por pequeños veleros. Los desembarcos conllevan el riesgo adicional de entrada de visitantes en el ASPA 140f. También se han encontrado presencia de restos de basuras orgánicas en las playas próximas

Si bien se ha limitado la cifra de visitantes a ***Baily Head*** por día y la duración máxima de permanencia, la acumulación de visitas a lo largo de la temporada puede ocasionar impactos acumulativos. A esto se sumaría que nuevas actividades de acceso a la pinguinera pudieran producir una variación en los impactos.

El resto de localizaciones de Isla Decepción no se consideran de interés, ya sea porque no reciben visitantes (la mayor parte de la isla), por tratarse de enclaves donde no se realizan *desembarcos* (***Fuelles de Neptuno, Bahía Fumarola***). No obstante, se han detectado por primera vez visitas a la pingüinera de **Punta Descubierta**, en la costa oeste de la isla, pudiendo incrementarse en el futuro.

2- Impactos detectados (*Benayas, 2010*)

2.1 Pisoteo de los suelos

En isla *Decepción* los suelos son volcánicos poco desarrollados con texturas muy gruesas, tipo andosol *(Bölter et al., 1999)*, el impacto se limita a un ligero cambio de color, un incremento de la compresión del sustrato y una mayor erosión superficial de los materiales de menor tamaño como consecuencia del arrastre eólico e hidrológico, ambos potenciados por la pendiente existente. Estos suelos presentan un escaso contenido en materia orgánica, por lo que la vegetación está ausente y la fauna edáfica es muy residual (en 12 muestras tomadas para el análisis de la abundancia de colémbolos, tan solo se encontró un único individuo).

2.2 Especies invasoras

Una tarea ineludible para las próximas campañas es el seguimiento de las especies exóticas que han sido detectadas hasta el momento en los ecosistemas terrestres de *Isla Decepción*. Hay que tener en cuenta que esta zona es muy sensible al establecimiento de especies exóticas, tanto vegetales como animales, debido a que presenta singularidades geológicas que elevan la temperatura de los suelos, permitiendo el asentamiento de especies adaptadas a las condiciones propias de latitudes menos extremas (Convey et al., 2000).

Respecto a las plantas, se han detectado recientemente dos especies de la familia de las *Asteraceas*, concretamente *Nassauvia magellanica y Gamochaeta nivalis*. Ambas están presentes en *Tierra del Fuego* y en el *sur Patagónico de Argentina y Chile*. Durante la campaña 2009-10 se ha llevado a cabo una campaña de erradicación de una cepa de la planta *Nassauvia magellanica* de las inmediaciones de la Base Britanica abandonada en *Bahía Balleneros* aunque no se tiente total seguridad de que pueda tratarse de un caso de especie invasora portada por el hombre.

Al margen de estas plantas, se han detectado otros organismos alóctonos en *Isla Decepción*, aunque su establecimiento no ha sido probado. Se trata de los colémbolos *Hypogastrura viatica*, *Folsomia candida y Protaphorura sp*. La primera especie ha protagonizado episodios de invasiones agresivas en diferentes islas subantárticas (*Greenslade, 2006)*, por lo que es imprescindible confirmar su presencia lo antes posible. Las otras dos especies de colémbolos fueron detectadas con anterioridad en la *Isla Decepción* (*Greenslade & Wise, 1984)*, aunque su establecimiento definitivo no ha sido probado hasta la fecha. El equipo de Convey ha tomado muestras en esta campaña para hacer seguimiento a estas especies.

2.3 Accidentes marítimos

En los últimos años, se han registrado accidentes de cruceros turísticos, tanto en la Antártida en su conjunto como en el caso concreto de Isla Decepción. Por ejemplo, el 10 de noviembre de 2006, el crucero turístico *Orlova* (110 pasajeros), varó en la playa por el temporal que se desató la noche anterior. Unos meses más tarde, el 1 de febrero de 2007, el barco turístico *Nordkapp* (297 pasajeros) colisionó con las rocas de la entrada a Decepción, en la zona de los Fuelles de Neptuno. La estructura de doble casco del buque fue un importante factor que evito el derrame de combustible en Puerto Foster

2.4 Basuras en playas

Tanto la actividad científica como los turistas generan pequeñas cantidades de residuos que terminan en las playas y senderos existentes, muchas veces de forma no intencionada. La mayoría de estos restos son fragmentos de madera de tamaño variable, aunque también se han observado elementos más singulares como tanques de metal. La segunda cuestión destacable es la diferencia entre el tipo de residuo predominante en cada área: los restos orgánicos fueron los más abundantes en *Bahía Telefono*, mientras que *en Caleta Péndulo* aparecían en mayor medida plásticos y en **Bahía Balleneros** había numerosos restos de madera y cristal. Quizás uno de los temas más críticos en *Decepción* es el estado de deterioro de los edificios de Bahía *Balleneros* que generan gran cantidad de restos de estos edificios –maderas, cristales, chapas, etc que se están dispersando por las playas internas de la Isla

3- El medio marino (C.Avila 2006,2009)

Existen estudios recientes que atestiguan la importancia de Bahía Balleneros como una de las zonas más ricas en invertebrados marinos de toda la isla, que por sus peculiares características deberían ser protegidas y conservadas (Barnes et al., 2008).

Proyectos realizados en el marco del Programa Polar Español (C. Avila 2006, 2009) han permitido corroborar que Balleneros es, en la isla, la zona más rica en fauna de invertebrados marinos, no solo en lo que se refiere a sustratos duros, sino también en cuanto a sustratos blandos. Inmersiones realizadas en estos Proyectos . por el grupo de C. Avila, confirman la presencia de comunidades bien desarrolladas de suspensívoros, incluyendo esponjas y corales blandos, así como de otros grupos como tunicados, gran variedad de moluscos, equinodermos, poliquetos, nemertinos, briozoos, etc. A estos invertebrados hay que añadir la gran variedad de algas que están ahora mismo en fase de estudio.

Todas esta fauna y flora marinas bentónicas de Balleneros, se podrían ver muy afectadas por el fondeo de barcos que remueven el fondo y arrancan la fauna y la flora del sustrato.con efectos devastadores en las comunidades bentónicas y recuperación muy lenta en muchos grupos de invertebrados.

Todo lo anterior hace que las comunidades de organismos que viven en estas zonas de poca profundidad, se pudieran ver gravemente afectadas por todas estas perturbaciones en la época más importante para sus ciclos de vida, cuando la mayoría se están reproduciendo.

BIBLIOGRAFIA

Avila C. (2006) Ecología: Ecología química de invertebrados antárticos *Proyecto de Investigacion. Ministerio de Ciencia e Innovación (España)*

Avila C. (2009) Actividad ecologica de productos naturales marinos de organismos bentonicos antarticos: experimentos de ecologia quimica in situ. *Proyecto de Investigacion. Ministerio de Ciencia e Innovación (España)*

Barnes, D.K.A., Linse, K., Enderlein, P., Smale, D., Fraser, K.P.P. & Brown, M. 2008.Marine richness and gradients at Deception Island, Antarctica. Antarctic Science, 20,271–279.

Benayas J (2009): Elaboración y puesta en marcha de un sistema de indicadores de seguimiento de las actividades humanas en la isla Decepción. *Proyecto de Investigacion. Ministerio de Ciencia e Innovación (España)*

Bölter, M. Blume, H.P. and Khun, D. 1999. Soils and their microbiological properties from a transect from Cape Horn to the Antarctic Peninsula. *Polar Bioscience*, 12: 54-67.

Convey, P., Greenslade, P. & Pugh, P.J.A. 2000. Terrestrial fauna of the South Sandwich Islands. *Journal of Natural History,* 34: 597–609.

Curry, C., McCarthy, J., Darragh, H., Wake, R., Todhunter, R., and Terris, J. (2001). Could tourists transmit infectious agents in Antarctica? Washington, D.C.: International Association of Antarctica Tour Operators (IAATO).

Greenslade, P. 2006. The invertebrates of Macquarie Island. Kingston*: Australian Antarctic Division, xvi þ 326 pp.*

Greenslade, P. & Wise, K.A.J. 1984. Additions to the collembolan fauna of the Antarctic. *Transactions of the Royal Society of South Australia, 108: 203–205.*

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Plan de gestión de la Zona Antártica Especialmente Protegida Nº 126, península Byers, isla Livingstone, islas Shetland del Sur

Plan de gestión de la Zona Antártica Especialmente Protegida Nº 126, península Byers, isla Livingstone, islas Shetland del Sur

1. La península Byers, isla Livingston, islas Shetland del Sur, fue designada originalmente Zona Especialmente Protegida (ZEP) Nº 10 en virtud de la Recomendación IV-10 de 1966. Por medio de la Recomendación VIII-4 (1975) se cambió la designación del sitio, que pasó a ser el Sitio de Especial Interés Científico (SEIC) Nº 6. A raíz de una propuesta de Chile y el Reino Unido se extendieron los límites de la Zona (Recomendación XVI-5 [1991]), y con la Medida 1 (2002) se agregaron valores que se consideran como motivos importantes para conferir protección especial a la Zona.

2. Entre los valores protegidos se encuentran la diversidad de la fauna y la flora, el sitio limnológico posiblemente más importante de las islas Shetland del Sur y la Península Antártica, y la mayor concentración de restos históricos de la Antártida, entre ellos artefactos de las expediciones balleneras de principios del siglo XIX.

3. Tras una visita del sitio en enero de 2010, Chile, España y el Reino Unido hicieron una revisión del plan de gestión y lo actualizaron. El plan revisado, adjunto al presente documento, se somete a la consideración del CPA.

4. Entre las modificaciones propuestas se encuentran algunos cambios de fondo en las disposiciones del plan de gestión existente, entre ellos los siguientes:

   Sección 1. Descripción de los valores que requieren protección. Reconocimiento de que, durante el Año Polar Internacional, se designó la península Byers como “sitio antártico de referencia internacional para ecosistemas terrestres, de agua dulce y costeros”.

   Sección 3. Actividades de gestión. Establecimiento de un Comité Coordinador Internacional para supervisar la implementación del plan de gestión y coordinar las actividades en la península Byers. Eso podría incluir la restricción del número de personas que pueden estar en tierra al mismo tiempo en la península Byers.

   Sección 6 (i). Límites. El suelo sin hielo expuesto recientemente como consecuencia del retroceso del domo Rotch quedará incluido automáticamente dentro de los límites de la ZAEP.

   Sección 6 (ii). Áreas restringidas y administradas en la Zona. El promontorio Ray y algunas áreas desglaciadas recientemente a lo largo del frente de hielo del domo Rotch han sido designados áreas restringidas. Estas áreas se consideran vedadas e inviolables hasta el próximo examen de este plan de gestión, excepto en lo que concierne a las investigaciones microbiológicas, a las cuales se aplicarán las medidas de cuarentena más estrictas. Esto se debe a que nunca han sido visitadas o han sido visitadas rara vez. Se prevé que las nuevas técnicas metagenómicas permitirán identificar la biodiversidad microbiana en una medida sin precedentes y responder a muchas preguntas fundamentales sobre la dispersión y distribución de microbios.

   Sección 6 (iii). Ubicación de estructuras dentro de la Zona y en sus proximidades. Hay un campamento internacional en las playas del sur, que consiste en dos cabañas “Melon”. El campamento, de cuyo mantenimiento se ocupa el Programa Polar de España, está a disposición de todas las Partes. Se ha designado un lugar para el aterrizaje de helicópteros y se han establecido medidas nuevas para reducir los efectos del pisoteo ocasionado por la circulación de peatones (**sección 7(i), Acceso a la Zona y circulación dentro de la misma).**

En la **sección 7 (vii), Toma o retiro de materiales que el titular del permiso no haya llevado a la Zona**, se propone hacer un inventario de los restos arqueológicos retirados anteriormente de la península Byers.

Asimismo, se agrega información más detallada sobre el clima, los lagos y arroyos, las aves y los mamíferos reproductores, y el impacto de los seres humanos.

5. Se somete el proyecto de plan de gestión a la consideración del Comité para la Protección del Medio Ambiente. En particular, se solicita al CPA que considere los cambios antedichos. Sin embargo, en vista de las extensas modificaciones que se propone hacer en el plan revisado, los proponentes recomiendan que se solicite al Grupo Subsidiario sobre Planes de Gestión que haga un examen más detallado del plan revisado en el período entre sesiones e informe al respecto en la XIV Reunión del CPA.

Management Plan for
Antarctic Specially Protected Area No. 126
BYERS PENINSULA, LIVINGSTON ISLAND, SOUTH SHETLAND ISLANDS

Introduction

The primary reason for the designation of Byers Peninsula (latitude 62°34'35" S, longitude 61°13'07" W), Livingston Island, South Shetland Islands, as an Antarctic Specially Protected Area (ASPA) is to protect the terrestrial and lacustrine habitats within the Area.

Byers Peninsula was originally designated as Specially Protected Area (SPA) No. 10 through Recommendation IV-10 in 1966. This area included the ice-free ground west of the western margin of the permanent ice sheet on Livingston Island, below Rotch Dome, as well as Window Island about 500 m off the northwest coast and five small ice-free areas on the south coast immediately to the east of Byers Peninsula. Values protected under the original designation included the diversity of plant and animal life, many invertebrates, a substantial population of southern elephant seals (*Mirounga leonina*), small colonies of Antarctic fur seals (*Arctocephalus gazella*), and the outstanding scientific values associated with such a large variety of plants and animals within a relatively small area.

Designation as an SPA was terminated through Recommendation VIII-2 and redesignation as a Site of Special Scientific Interest (SSSI) was made through Recommendation VIII-4 (1975, SSSI No. 6). The new designation as an SSSI more specifically sought to protect four smaller ice-free sites on the peninsula of Jurassic and Cretaceous sedimentary and fossiliferous strata, considered of outstanding scientific value for study of the former link between Antarctica and other southern continents. Following a proposal by Chile and the United Kingdom, the SSSI was subsequently extended through Recommendation XVI-5 (1991) to include boundaries similar to those of the original SPA: i.e. the entire ice-free ground of Byers Peninsula west of the margin of the permanent Livingston Island ice sheet, including the littoral zone, but excluding Window Island and the five southern coastal sites originally included, as well as excluding all offshore islets and rocks. Recommendation XVI-5 noted that in addition to the special geological value, the Area was also of considerable biological and archaeological importance.

While the particular status of designation and boundaries have changed from time to time, Byers Peninsula has in effect been under special protection for most of the modern era of scientific activity in the region. Recent activities within the Area have been almost exclusively for scientific research. Most visits and sampling within the Area, since original designation in 1966, have been subject to Permit conditions, and some areas (e.g. Ray Promontory) have been rarely visited. During the International Polar Year, Byers Peninsula was established as an 'International Antarctic Reference Site for Terrestrial, Freshwater and Coastal Ecosystems' (Quesada et al 2009). During this period baseline data relating to terrestrial, limnetic and coastal ecosystems was established, including permafrost characteristics, geomorphology, vegetation extent, limnetic diversity and functioning, marine mammal and bird diversity, microbiology, and coastal marine invertebrate diversity. The archaeological values of Byers Peninsula have been described as unique in possessing the greatest concentration of historical sites in Antarctica, namely the remains of refuges, together with contemporary artefacts and shipwrecks of early nineteenth century sealing expeditions (see Map 2).

Byers Peninsula makes a substantial contribution to the Antarctic protected areas system as it (a) contains a particularly wide diversity of species, (b) is distinct from other areas due to its numerous lakes, freshwater ponds and streams, (c) is of great ecological importance and represents the most significant limnological site in the region, (d) is vulnerable to human interference, in particular, due to the oligotrophic nature of the lakes which are highly sensitive to pollution and (e) is of great scientific interest across a range of disciplines. While some of these quality criteria are represented in other ASPAs in the region, Byers Peninsula is unique in possessing a high number of different criteria within one area. While Byers Peninsula is protected primarily for its outstanding environmental values (specifically its biological diversity and terrestrial and lake ecosystems) the Area contains a combination of other values including scientific (i.e. for terrestrial biology, limnology, ornithology, palaeolimnology, geomorphology and geology), historic (artefacts and refuge remains of early sealers), wilderness (e.g. Ray Promontory) and on-going scientific values that may benefit from the Area's protection.

The ice-free ground of Byers Peninsula is surrounded on three sides by ocean and the Rotch Dome glacier to the east. The Area has been designated to protect values found within the ice-free ground on Byers Peninsula. To fulfil this objective a portion of Rotch Dome has been included within the ASPA to ensure newly exposed ice-free ground, (resulting from any retreat of Rotch Dome), will be within the boundaries of the ASPA. In addition, the northwestern Rotch Dome including adjacent de-glaciated ground and Ray Promontory have been designated as restricted zones to allow microbiological studies that required higher quarantine standards than considered necessary within the rest of the Area. The Area (84.7 km^2) is considered to be of sufficient size to provide adequate protection of the values described below.

1. Description of values to be protected

The Management Plan attached to Measure 1 (2002) noted values considered important as reasons for special protection of the Area. The values recorded in the original Management Plans are reaffirmed. These values are set out as follows:

- The described terrestrial flora and fauna is of exceptional diversity, with one of the broadest representations of species known in the maritime Antarctic. For example, sparse but diverse flora of calcicolous and calcifuge plants and cyanobacteria are associated with the lavas and basalts, respectively, and several rare cryptogams and the two native vascular plants (*Deschampsia antarctica* and *Colobanthus quitensis*) occur at several sites.
- With over 60 lakes, numerous freshwater pools and a great variety of often extensive streams, it is the most significant limnological site in the South Shetland Islands – and perhaps the Antarctica Peninsula region – and also one which has not been subjected to significant levels of human disturbance.
- *Parochlus steinenii* (the only native winged insect in Antarctica) is of limited distribution in the South Shetland Islands. The only other native dipteral, the wingless midge *Belgica antarctica*, has a very restricted distribution on the Antarctic Peninsula. Both species are abundant at several of the lakes and pools on Byers Peninsula.
- Unusually extensive cyanobacterial mats dominated by *Phormidium* sp.and other species, particularly on the upper levels of the central Byers Peninsula plateau, are the best examples so far described in the maritime Antarctic.
- The breeding avifauna within the Area is diverse, including two species of penguin [chinstrap (*Pygoscelis antarctica)* and gentoo (*P. papua*)], Antarctic tern (*Sterna vittata*), Wilson's storm petrels (*Oceanites oceanicus*), cape petrels (*Daption capense*), kelp gulls (*Larus dominicanus*), southern giant petrels (*Macronectes giganteus*), black-bellied storm petrels (*Fregetta tropica*), blue-eyed cormorants (*Phalacrocorax atriceps*), brown skuas (*Catharacta loennbergi*), and sheathbills (*Chionis alba*).
- The lakes and their sediments constitute one of the most important archives for study of the Holocene palaeoenvironment in the Antarctic Peninsula region, as well as for establishing a regional Holocene tephrachronology.
- Well-preserved sub-fossil whale bones are present in raised beaches, which are important for radiocarbon dating of beach deposits.
- The ice-free sites on the peninsula with exposed Jurassic and Cretaceous sedimentary and fossiliferous strata, are considered of outstanding scientific value for study of the former link between Antarctica and other southern continents.

2. Aims and objectives

Management at Byers Peninsula aims to:

- avoid degradation of, or substantial risk to, the values of the Area by preventing unnecessary human disturbance;
- allow scientific research on the terrestrial and lacustrine ecosystems, marine mammals, avifauna, coastal ecosystems and geology;
- allow other scientific research within the Area provided it is for compelling reasons which cannot be served elsewhere;
- allow archaeological research and measures for artefact protection, while protecting historic artefacts present within the Area from unnecessary destruction, disturbance, or removal;

- prevent or minimise the introduction to the Area of alien plants, animals and microbes;
- minimise the possibility of the introduction of pathogens which may cause disease in fauna within the Area; and
- allow visits for management purposes in support of the aims of the management plan.

3. Management activities

The following management activities shall be undertaken to protect the values of the Area:

- A map showing the location of the Area and stating the special restrictions that apply, shall be displayed prominently at Base Juan Carlos I (Spain) and St. Kliment Ochridski Station (Bulgaria) on Hurd Peninsula, where copies of this management plan shall be made available.
- Markers, signs, fences or other structures erected within the Area for scientific or management purposes shall be secured and maintained in good condition.
- Visits shall be made as necessary to assess whether the Area continues to serve the purposes for which it was designated and to ensure management and maintenance measures are adequate.

Byers Peninsula has been described as extremely sensitive to human impact (Tejedo et al 2009). The Area was designated as an ASPA to protect a diverse range of values present within the Area. As a result, it attracts scientists (representing a diverse range of disciplines) and archaeologists from a number of Treaty nations. The high number of people present in the Area at peak times (mid-summer) means there is potential for the environmental values of the area to be negatively impacted upon by human activities, for example by potentially increasing (i) the size and number of camping location, (ii) the trampling of vegetation, (iii) the disturbance of native wildlife (iv) the generation of waste and (v) the need for fuel storage. Consequently, when making plans for field work within the Area, Parties are **strongly encouraged** to liaise with other nations likely to be operating in the Area that season and co-ordinate activities to keep environmental impacts, including cumulative impacts, to an absolute minimum (e.g. fewer than c. 12 people in the International Field Camp at any one time).

All Parties are strongly encouraged to use the established International Field Camp (located on South Beaches, 62º39'49.7" S, 61º05'59.8' W), to reduce the creation of new camping sites that would increase levels of human impacts within the Area. Two melon huts are found within the camp (one set up for scientific research, the other for domestic activities; both huts are managed by Spain). The melon huts are available to all Treaty Parties, should they wish to use them. Parties should liaise with Spain to co-ordinate access to the melon huts.

4. Period of designation

Designated for an indefinite period.

5. Maps and photographs

Map 1: Byers Peninsula ASPA No. 126 in relation to the South Shetland Islands, showing the location of Base Juan Carlos I (Spain) and St. Kliment Ochridski Station (Bulgaria), and showing the location of protected areas within 75 km of the Area. <u>Inset:</u> the location of Livingston Island along the Antarctica Peninsula.

Map 2: Byers Peninsula ASPA No. 126 topographic map. Map specifications: Projection UTM Zone 20S; Spheroid: WGS 1984; Datum: Mean Sea Level. Horizontal accuracy of control: ±0.05 m. Vertical contour interval 50 m.

6. Description of the Area

6(i) Geographical coordinates, boundary markers and natural features

BOUNDARIES

The Area encompasses:

- Byers Peninsula and all ice-free ground and ice sheet west of longitude 60°53’45’’ W, including Clark Nunatak and Rowe Point;
- the near-shore marine environment extending 10 m offshore from the low tide water line; and
- Demon Island and Sprite Island, adjacent to the southern shoreline of Devils Point, but excluding all other offshore islets, including Rugged Island, and rocks (Map 2).

The linear eastern boundary follows longitude 60°53’45’’ W to ensure newly exposed ice-free ground resulting from the retreat of Rotch Dome, which may contain scientifically useful opportunities and new habitats for colonization studies, will be within the boundaries of the ASPA.

No boundary markers are in place.

GENERAL DESCRIPTION

Byers Peninsula (between latitudes 62°34'35" and 62°40'35" S and longitudes 60°53’45’’" and 61°13'07" W, 84.7 km^2) is situated at the west end of Livingston Island, the second-largest of the South Shetland Islands (Map 1). The ice-free area on the peninsula has a central west-east extent of about 9 km and a NW-SE extent of 18.2 km, and is the largest ice-free area in the South Shetland Islands. The peninsula is generally of low, gently rolling relief, although there are a number of prominent hills ranging in altitude between 80 – 265 m (Map 2). The interior is dominated by a series of extensive platforms at altitudes of up to 105 m, interrupted by isolated volcanic plugs such as Chester Cone (188 m) and Negro Hill (143 m) (Thomson and López-Martínez 1996). There is an abundance of rounded, flat landforms resulting from marine, glacial and periglacial erosional processes. The most rugged terrain occurs on Ray Promontory, a ridge forming the northwest-trending axis of the roughly ‘Y’-shaped peninsula. Precipitous cliffs surround the coastline at the northern end of Ray Promontory with Start Hill (265 m) at the NW extremity being the highest point on the peninsula.

The coast of Byers Peninsula has a total length of 71 km (Map 2). Although of generally low relief, the coast is irregular and often rugged, with numerous headlands, cliffs, offshore islets, rocks and shoals. Byers Peninsula is also notable for its broad beaches, prominent features on all three coasts (Robbery Beaches in the north, President Beaches in the west, and South Beaches). The South Beaches are the most extensive; extending 12 km along the coast and up to almost 0.9 km in width, these are the largest in the South Shetland Islands (Thomson and López-Martínez 1996). For a detailed description of the geology and biology of the Area see Annex 1.

Resolution 3 (2008) recommended that the “Environmental Domains Analysis for the Antarctic Continent”, be used as a dynamic model for the identification of Antarctic Specially Protected Areas within the systematic environmental-geographical framework referred to in Article 3(2) of Annex V of the Protocol. Using this model, Byers Peninsula is predominantly Environment Domain G (Antarctic Peninsula off-shore islands geologic), which is described as “*a very small terrestrial environment focused around the Antarctic Peninsula and associated offshore islands such as Deception Island. At 966 km^2 it is by far the smallest environment within the classification. The environment consists entirely of ice-free land cover and contains a combination of three geological units - sedimentary (2%), intrusive (24%), and volcanic (28%). Climatically the environment is the warmest in the classification with an average air temperature of only -3.29°C, has the smallest seasonal range at -8.82°C, and receives the highest level of solar radiation at 10.64 MJ/m2/day. The average wind speed within the environment is moderate, at 13.86 m/sec. The environment is moderately sloping with an average slope of 13.41°. Well-known locations the environment covers include parts of ice free areas on South Shetland Islands such as Fildes Peninsula on King George Island, and small points on the Antarctic Peninsula along Davis Coast’*. The scarcity of Environment G, relative to the other environmental domain areas, means that substantial efforts have been made to conserve the values found within this environment type elsewhere: other protected areas containing Domain G include ASPAs 109, 111, 112, 114, 125, 128, 140, 145, 149, 150, and 152 and ASMAs 1 and 4.

The permanent ice of Rotch Dome comes under Environment Domain E, which is described as “*a moderately sized ice sheet environment focussed around the Antarctic Peninsula as far south as latitude 73°S. The size of the environment (173,130 km^2) is moderate when compared with other environments. The environment consists entirely of ice sheet and contains no mapped geology. Climatically the environment is warm when compared across the continent and is the warmest of the environments that contain only ice sheet. Environment E is ranked ninth warmest in average air temperature (-14.06 °C), fourth smallest in seasonal range (-15.04 °C), and seventh in the amount of solar radiation (9.85 MJ/m^2/day). The average* *wind speed within the environment is low ranking, 17th out of 21 environments (10.28 m/s). The environment is a moderately sloping environment with an average slope of 15.01°. Well-known locations the environment covers include the glacierised parts of South Orkney, South Shetland (including Deception), Snow Hill, Brabant, Anvers, Adelaide and Alexander Islands as well as the Antarctic Peninsula north of 73°S'*. Other protected areas containing Domain E include ASPAs 113, 114, 117, 126, 128, 129, 133, 134, 139, 147, 149, 152 and ASMAs 1 and 4.

6(ii) Access to the Area

- Access shall be by helicopter or small boat.
- There are no special restrictions on boat landings from the sea, or that apply to the sea routes used to move to and from the Area. Due to the large extent of accessible beach around the Area, landing is possible at many locations. Nevertheless, if possible, landing of cargo and scientific equipment should be close to the International Field Camp located at Southern Beaches (62º39'49.7" S, 61º05'59.8' W; see 6(*iii*) for further details).
- A designated helicopter landing site is located at 62º39'36.4" S, 61º05'48.5' W, to the east of the International Field Camp.
- Under exceptional circumstances necessary for purposes consistent with the objectives of the Management Plan, helicopters may land elsewhere within the Area, although landings should, where practicable, be made on ridge and raised beach crests.
- No helicopter lands shall be made within the restricted zones [see section 6(*v*)].
- Helicopters should avoid sites where there are concentrations of birds (e.g. Devils Point, Lair Point and Robbery Beaches) or well-developed vegetation (e.g. large stands of mosses near President and South Beaches).
- To avoid disturbance of wildlife, aircraft should avoid landing within an over-flight restriction zone extending ¼ nautical mile (c. 460 m) inland from the coast during the period 1 October – 30 April inclusive (see Map 2). The only exception to this is the designated helicopter landing site at 62º39'36.4" S, 61º05'48.5'W.
- Within the over-flight restriction zone the operation of aircraft should be carried out, as a minimum requirement, in compliance with the 'Guidelines for the Operation of Aircraft near Concentrations of Birds' contained in Resolution 2 (2004). In particular, aircraft should maintain a vertical height of 2000 ft (~ 610 m) AGL and cross the coastline at right angles where possible. When conditions require aircraft to fly at lower elevations than recommended in the guidelines, aircraft should maintain the maximum elevation possible and minimise the time taken to transit the coastal zone.
- Use of helicopter smoke grenades is prohibited within the Area unless absolutely necessary for safety. If used all smoke grenades should be retrieved.

6(iii) Location of structures within and adjacent to the Area

An International Field Camp is located at South Beaches, at 62º39'49.7" S, 61º05'59.8' W. It is comprised of two fibreglass 'melon huts'. It is maintained by the Spanish Polar Programme and is available for use by all Parties. The locations of 19th Century sealers remains, including refuges and caves used for shelter are given in Smith and Simpson (1987) (see Map 2). Several cairns marking sites used for topographical survey are also present within the Area, predominantly on high points.

The nearest scientific research stations are 30 km east at Hurd Peninsula, Livingston Island [Base Juan Carlos I (Spain) and St Kliment Ochridski (Bulgaria)].

6(iv) Location of other protected areas within close proximity of the Area

The nearest protected areas to Byers Peninsula are: Cape Shirreff (ASPA No. 149) which lies about 20 km to the northeast, Deception Island (ASMA No. 4), Port Foster and other parts of Deception Island (ASPAs No. 140, 145) which are approximately 40 km SSE and 'Chile Bay' (Discovery Bay) (ASPA No. 144), which is about 70 km to the east at Greenwich Island (Map 1).

6(v) Restricted and managed zones within the Area

Some zones on Byers Peninsula are thought to have been visited only very rarely, or never. New metagenomic techniques are predicted to allow future identification of microbial biodiversity (bacteria, fungi and viruses) to an unprecedented level, allowing many fundamental questions regarding microbial dispersal and distribution to be answered. Restricted zones have been designated that are of scientific importance to Antarctic microbiology and greater restriction is placed on access with the aim of preventing microbial or other contamination by human activity:

- In keeping with this aim, within the restricted zones sterile protective over-clothing shall be worn. The protective clothing shall be put on immediately prior to entering the restricted zones. Spare boots, previously cleaned using a biocide then sealed in plastic bags, shall be unwrapped and put on just before entering the restricted zones. If accessing the restricted zones by boat, protective clothing shall be put on immediately upon landing.
- To the greatest extent possible, all sampling equipment, scientific apparatus and markers brought into the restricted zones shall have been sterilized, and maintained in a sterile condition, before being used within the Area. Sterilization should be by an accepted method, including UV radiation, autoclaving or by surface sterilisation using 70% ethanol or a commercially available biocide (e.g. Virkon®).
- General equipment includes harnesses, crampons, climbing equipment, ice axes, walking poles, ski equipment, temporary route markers, pulks, sledges, camera and video equipment, rucksacks, sledge boxes and all other personal equipment. To the maximum extent practicable, all equipment used or brought into the restricted zones shall have been thoroughly cleaned and sterilized at the originating Antarctic station or ship. Equipment shall have been maintained in this condition before entering the restricted zones, preferably by sealing in sterile plastic bags or other clean containers.
- Scientists from disciplines other than microbiology are permitted to enter the restricted areas, but shall adhere to the quarantine measures detailed above.
- Camping within the restricted zones is not permitted.
- Helicopter landings within the restricted zones are not permitted.
- If access to the restricted zones is required for research or for emergency reasons, a detailed record of where visitation occurred (preferably using GPS technology) and the specific activities, should be submitted to the appropriate national authority and included in the Exchange of Information Annual Report, preferably through the Electronic Information Exchange System (EIES).

The restricted zones are:

1. North-western Rotch Dome and adjacent deglaciated ground. The restricted zone includes all land and ice sheet within an area bordered to the east by longitude 60º53'45"W, to the west by longitude 60º58'48" W, to the south by latitude 62º38'30"S, and the northern boundary follows the coastline (see Map 2).
2. Ray Promontory. The restricted zone includes all land and permanent ice northwest of a straight line crossing the Promontory from 62º37’S, 61º08’W (marked by a small coastal lake) to 62º36’S, 61º06’W. Within the Ray Promontory restricted zone, access to archaeological remains located on the coast is permitted without the need for quarantine precautions required elsewhere within the restricted zone. Access to inland areas beyond the coastal archaeological remains is not permitted without quarantine measures, detailed in this section, in place. Preferably, access to the archaeological remains shall be from the sea using small boats. Access to the archaeological remains on foot is also permitted without the need for the additional quarantine measures, by following the coastline from the unrestricted area of the Byers Peninsula ASPA to the southeast. Access to the archaeological remains shall be solely for archaeological investigations, authorised by the appropriate national authority.

7. Terms and conditions for entry permits

Entry into the Area is prohibited except in accordance with a Permit issued by an appropriate national authority.

7(i) General permit conditions

Conditions for issuing a Permit to enter the Area are that:

- it is issued only for scientific study of the ecosystem, geology, palaeontology or archaeology of the Area, or for compelling scientific reasons that cannot be served elsewhere; or
- it is issued for essential management purposes consistent with management plan objectives such as inspection, maintenance or review;
- the actions permitted will not jeopardise the ecological, geological, historical or scientific values of the Area;
- the sampling proposed will not take, remove or damage such quantities of soil, rock, native flora or fauna that their distribution or abundance on Byers Peninsula would be significantly affected;
- any management activities are in support of the objectives of the management plan;
- the actions permitted are in accordance with the management plan;
- the Permit, or an authorised copy, shall be carried within the Area;
- a visit report shall be supplied to the authority named in the Permit;
- permits shall be issued for a stated period; and
- the appropriate authority should be notified of any activities/measures undertaken that were not included in the authorised Permit.

7(ii) Access to and movement within or over the Area

- Land vehicles are prohibited within the Area.
- Movement within the Area shall be on foot unless under exceptional circumstances when helicopter may be used.
- All movement shall be undertaken carefully so as to minimise disturbance to archaeological remains, animals, soils, geomorphological features and vegetated surfaces, walking on rocky terrain or ridges if practical to avoid damage to sensitive plants, patterned ground and waterlogged soils.
- Pedestrian traffic should be kept to the minimum consistent with the objectives of any permitted activities and every reasonable effort should be made to minimise trampling effects. Where possible, existing tracks should be used to transit the area (Map 2). If no track exists, care should be taken to avoid creation of new tracks. Research has shown that vegetation on Byers Peninsula can recover if fewer than 200 transits are made over it in a single season (Tejedo et al 2009). Pedestrian routes over vegetated ground should therefore be chosen depending on the forecasted number of transits (i.e. number of people × transits per day × number of days). When the number of transits on the same track is expected to be less than 200 in the same season, the track should be clearly identified and transits always made along the track. When the number is expected to be larger than 200 in a season, then the route should not be fixed along a single track, but transits should be done across a wide belt (i.e. multiple tracks, each with fewer than 200 transits), to diffuse the impact and allow quicker recovery of trampled vegetation.
- Conditions for use of helicopters within the Area are described in section 6(*ii*)
- Pilots, air and boat crew, or other people on aircraft or boats, are prohibited from moving on foot beyond the immediate vicinity of their landing site unless specifically authorised by Permit.
- Restrictions on access and movement within the restricted zones are described in section 6(*v*)

7(iii) Activities which may be conducted in the Area

- Compelling scientific research which cannot be undertaken elsewhere and that will not jeopardise the ecosystem or values of the Area or interfere with existing scientific studies.
- Archaeological research.
- Essential management activities, including monitoring.

7(iv) Installation, modification or removal of structures

No new structures are to be erected within the Area, or scientific equipment installed, except for compelling scientific or management reasons and for a pre-established period, as specified in a permit. Installation (including site selection), maintenance, modification or removal of structures and equipment shall be undertaken in a manner that minimises disturbance to the values of the Area. All structures or scientific equipment installed in the Area shall be clearly identified by country, name of the principal investigator and year of installation. All such items should be free of organisms, propagules (e.g. seeds, eggs) and non-sterile soil, and be made of materials that can withstand the environmental conditions and pose minimal risk of contamination of the Area. Removal of specific structures or equipment for which the Permit has expired shall be a condition of the Permit. Permanent structures or installations are prohibited.

7(v) Location of field camps

In order to minimise the area of ground within the ASPA impacted by camping activities, camps should be within the immediate vicinity of the International Field Camp (62º39'49.7" S, 61º05'59.8" W). When necessary for purposes specified in the Permit, temporary camping beyond the International Field Camp is allowed within the Area. Camps should be located on non-vegetated sites, such as on the drier parts of the raised beaches, or on thick (>0.5 m) snow-cover when practicable, and should avoid concentrations of breeding birds or mammals. Camping within 50 m of any sealers' refuge or shelter is prohibited. Previously used campsites should be re-used where practical, unless the guidance above suggests that they were inappropriately located. Camping within the restricted zones is not permitted.

7(vi) Restrictions on materials and organisms which can be brought into the Area

The deliberate introduction of animals, plant material, microorganisms and non-sterile soil into the Area shall not be permitted. Precautions shall be taken to prevent the accidental introduction of animals, plant material, micro-organisms and non-sterile soil from other biologically distinct regions (within or beyond the Antarctic Treaty area). In view of the presence of breeding bird colonies on Byers Peninsula, no poultry products, including wastes from such products and products containing uncooked dried eggs, shall be released into the Area or into the adjacent sea.

No herbicides or pesticides shall be brought into the Area. Any other chemicals, including radio-nuclides or stable isotopes, which may be introduced for scientific or management purposes specified in the Permit, shall be removed from the Area at or before the conclusion of the activity for which the Permit was granted. Release of radio-nuclides or stable isotopes directly into the environment in a way that renders them unrecoverable should be avoided. Fuel or other chemicals shall not be stored in the Area unless specifically authorised by Permit condition. They shall be stored and handled in a way that minimises the risk of their accidental introduction into the environment. Materials introduced into the Area shall be for a stated period only and shall be removed by the end of that stated period. If release occurs which is likely to compromise the values of the Area, removal is encouraged only where the impact of removal is not likely to be greater than that of leaving the material *in situ*. The appropriate authority should be notified of anything released and not removed that was not included in the authorised Permit.

7(vii) Taking of, or harmful interference with, native flora or fauna

Taking of or harmful interference with native flora or fauna is prohibited, except by Permit issued in accordance with Annex II to the Protocol on Environmental Protection to the Antarctic Treaty. Where taking of or harmful interference with animals is involved, the *SCAR Code of Conduct for the Use of Animals for Scientific Purposes in Antarctica* should be used as a minimum standard.

7(viii) The collection or removal of materials not brought into the Area by the Permit holder

Collection or removal of anything not brought into the Area by the permit holder shall only be in accordance with a Permit and should be limited to the minimum necessary to meet scientific, archaeological or management needs.

Unless specifically authorized by permit, visitors to the Area are prohibited from interfering with or from handling, taking or damaging any historic anthropogenic material meeting the criteria in Resolution 5 (2001). Similarly, relocation or removal of artefacts for the purposes of preservation, protection or to re-establish historical accuracy is allowable only by permit. The appropriate national authority shall be informed of the location and nature of any newly identified anthropogenic materials.

Other material of human origin likely to compromise the values of the Area which was not brought into the Area by the permit holder or otherwise authorised, may be removed from the Area unless the environmental impact of the removal is likely to be greater than leaving the material in situ; if this is the case the appropriate Authority must be notified and approval obtained.

7(ix) Disposal of waste

As a minimum standard all waste shall be disposed of in accordance with Annex III to the Protocol on Environmental Protection to the Antarctic Treaty. In addition, all wastes, including all solid human waste, shall be removed from the Area. Liquid human wastes may be disposed of into the sea. Solid human waste should not be disposed of to the sea as the near-shore reefs will prevent dispersal, but shall be removed from the Area. No human waste shall be disposed of inland as the oligotrophic characteristics of the lakes and other water-bodies on the plateau can be compromised by even a small quantity of human waste, including urine.

7(x) Measures that are necessary to ensure that the aims and objectives of the management plan can continue to be met

Permits may be granted to enter the Area to:

- carry out monitoring and site inspection activities, which may involve the collection of data and/or a small number of samples for analysis or review;
- erect or maintain signposts, structures or scientific equipment; or
- carry out protective measures.

Any specific sites of long-term monitoring shall be appropriately marked on site and on maps of the Area. A GPS position should be obtained for lodgement with the Antarctic Data Directory System through the appropriate national authority.

To help maintain the ecological and scientific values of the Area, visitors shall take special precautions against introductions. Of particular concern are microbial, animal or vegetation introductions sourced from soils from other Antarctic sites, including stations, or from regions outside Antarctica. To the maximum extent practicable, visitors shall ensure that footwear, clothing and any equipment – particularly camping and sampling equipment – is thoroughly cleaned before entering the Area. Poultry products and other introduced avian products, which may be a vector of avian diseases, shall not be released into the Area.

7(xi) Requirements for reports

The principal permit holder for each visit to the Area shall submit a report to the appropriate national authority as soon as practicable, and no later than six months after the visit has been completed. Such reports should include, as appropriate, the information identified in the visit report form contained in the Guide to the Preparation of Management Plans for Antarctic Specially Protected Areas. If appropriate, the national authority should also forward a copy of the visit report to the Party that proposed the Management Plan, to assist in managing the Area and reviewing the Management Plan. Wherever possible, Parties should deposit the original or copies of the original visit reports, in a publicly accessible archive to maintain a record of usage, for the purpose of any review of the Management Plan and in organising the scientific use of the Area.

8. Supporting documentation

Bañón, M., Justel M. A., Quesada, A. 2006. Análisis del microclima de la península Byers, isla Livingston, Antártida, en el marco del proyecto LIMNOPOLAR. In: *Aplicaciones meteorológicas*. Asociación Meteorológica Española.

Birnie, R.V., Gordon, J.E. 1980. Drainage systems associated with snow melt, South Shetland Islands, Antarctica. *Geografiska Annaler* **62A**: 57-62.

Björck, S., Hakansson, H, Zale, R., Karlén, W., Jönsson, B.L. 1991. A late Holocene lake sediment sequence from Livingston Island, South Shetland Islands, with palaeoclimatic implications. *Antarctic Science* **3**: 61-72.

Björck, S., Sandgren, P., Zale, R. 1991. Late Holocene tephrochronology of the Northern Antarctic Peninsula. *Quaternary Research* **36**: 322-28.

Björck, S., Hjort, C, Ingólfsson, O., Skog, G. 1991. Radiocarbon dates from the Antarctic Peninsula - problems and potential. In: Lowe, J.J. (ed.), *Radiocarbon dating: recent applications and future potential. Quaternary Proceedings* 1, Quaternary Research Association, Cambridge. pp 55-65.

Björck, S., Håkansson, H., Olsson, S., Barnekow, L., Janssens, J. 1993. Palaeoclimatic studies in South Shetland Islands, Antarctica, based on numerous stratigraphic variables in lake sediments. *Journal of Paleolimnology* **8**: 233-72.

Björck, S., Zale, R. 1996. Late Holocene tephrochronology and palaeoclimate, based on lake sediment studies. In: López-Martínez, J., Thomson, M. R. A., Thomson, J.W. (eds.) *Geomorphological map of Byers Peninsula, Livingston Island*. BAS GEOMAP Series Sheet 5-A, 43-48. British Antarctic Survey, Cambridge.

Björck, S., Hjort, C., Ingólfsson, O., Zale, R., Ising, J. 1996. Holocene deglaciation chronology from lake sediments. In: López-Martínez, J., Thomson, M. R. A., Thomson, J.W. (eds.) *Geomorphological map of Byers Peninsula, Livingston Island*. BAS GEOMAP Series Sheet 5-A, 49-51. British Antarctic Survey, Cambridge.

Block, W., Starý, J. 1996. Oribatid mites (Acari: Oribatida) of the maritime Antarctic and Antarctic Peninsula. *Journal of Natural History* **30**: 1059-67.

Bonner, W.N., Smith, R.I.L. (Eds) 1985. *Conservation areas in the Antarctic.* SCAR, Cambridge: 147-56.

Booth, R.G., Edwards, M., Usher, M.B. 1985. Mites of the genus Eupodes (Acari, Prostigmata) from maritime Antarctica: a biometrical and taxonomic study. *Journal of the Zoological Society of London (A)* **207**: 381-406.

Carlini, A.R., Coria, N.R., Santos, M.M., Negrete, J., Juares, M.A., Daneri, G.A. 2009. Responses of *Pygoscelis adeliae* and *P. papua* populations to environmental changes at Isla 25 de Mayo (King George Island). *Polar Biology* **32**: 1427-1433.

Convey, P., Greenslade, P. Richard, K.J., Block, W. 1996. The terrestrial arthropod fauna of the Byers Peninsula, Livingston Island, South Shetland Islands - Collembola. *Polar Biology* **16**: 257-59.

Covacevich, V.C. 1976. Fauna valanginiana de Peninsula Byers, Isla Livingston, Antartica. *Revista Geologica de Chile* **3**: 25-56.

Crame, J.A. 1984. Preliminary bivalve zonation of the Jurassic-Cretaceous boundary in Antarctica. In: Perrilliat, M. de C. (Ed.) *Memoria, III Congreso Latinamerico de Paleontologia, Mexico, 1984. Mexico City*, Universidad Nacional Autonoma de Mexico, Instituto de Geologia. pp 242-54.

Crame, J.A. 1985. New Late Jurassic Oxytomid bivalves from the Antarctic Peninsula region. *British Antarctic Survey Bulletin* **69**: 35-55.

Crame, J.A. 1995. Occurrence of the bivalve genus Manticula in the Early Cretaceous of Antarctica. *Palaeontology* **38** Pt. 2: 299-312.

Crame, J.A. 1995. A new Oxytomid bivalve from the Upper Jurassic–Lower Cretaceous of Antarctica. *Palaeontology* **39** Pt. 3: 615-28.

Crame, J.A. 1996. Early Cretaceous bivalves from the South Shetland Islands, Antarctica. *Mitt. Geol-Palaont. Inst. Univ. Hamburg* **77**: 125-127.

Crame, J.A., Kelly, S.R.A. 1995. Composition and distribution of the Inoceramid bivalve genus *Anopaea*. *Palaeontology* **38** Pt. 1: 87-103.

Crame, J.A., Pirrie, D., Crampton, J.S., Duane, A.M. 1993. Stratigraphy and regional significance of the Upper Jurassic - Lower Cretaceous Byers Group, Livingston Island, Antarctica. *Journal of the Geological Society* **150** Pt. 6: 1075-87.

Croxall, J.P., Kirkwood, E.D. 1979. *The distribution of penguins on the Antarctic Peninsula and the islands of the Scotia Sea.* British Antarctic Survey, Cambridge.

Davey, M.C. 1993. Carbon and nitrogen dynamics in a maritime Antarctic stream. *Freshwater Biology* **30**: 319-30.

Davey, M.C. 1993. Carbon and nitrogen dynamics in a small pond in the maritime Antarctic. *Hydrobiologia* **257**: 165-75.

Duane, A.M. 1994. Preliminary palynological investigation of the Byers Group (Late Jurassic-Early Cretaceous), Livingston Island, Antarctic Peninsula. *Review of Palaeobotany and Palynology* **84**: 113-120.

Duane, A.M. 1996. Palynology of the Byers Group (Late Jurassic-Early Cretaceous) Livingston and Snow Islands, Antarctic Peninsula: its biostratigraphical and palaeoenvironmental significance. *Review of Palaeobotany and Palynology* **91**: 241-81.

Duane, A.M. 1997. Taxonomic investigations of Palynomorphs from the Byers Group (Upper Jurassic-Lower Cretaceous), Livingston and Snow Islands, Antarctic Peninsula. *Palynology* **21**: 123-144.

Ellis-Evans, J.C. 1996. Biological and chemical features of lakes and streams. In: López-Martínez, J., Thomson, M. R. A., Thomson, J.W. (eds.) *Geomorphological map of Byers Peninsula, Livingston Island*. BAS GEOMAP Series Sheet 5-A, 20-22. British Antarctic Survey, Cambridge.

Fernández-Valiente, E., Camacho, A., Rochera, C., Rico, E., Vincent, W. F., Quesada, A. 2007 Community structure and physiological characterization of microbial mats in Byers Peninsula, Livingston Island (South Shetland islands, Antarctica). *FEMS Microbiology Ecology* **59**: 377- 385

Gil-Delgado, J.A., Villaescusa, J.A., Diazmacip, M.E., Velazquez, D., Rico, E., Toro, M., Quesada, A., Camacho, A. Is the southern elephant seal *mirounga leonina* population on the Byers Peninsula (Livingston Island, South Shetland Islands) increasing? *Polar Biology* (submitted)

Gil-Delgado, J.A., González-Solis, J., Barbosa, A. 2010. Breeding birds populations in Byers Peninsula (Livingston Is., South Shetlands Islands. 18th International Conference of the European Bird Census Council. 22-26 March. Caceres. Spain.

González-Ferrán, O., Katsui, Y., Tavera, J. 1970. Contribución al conocimiento geológico de la Península Byers, Isla Livingston, Islas Shetland del Sur, Antártica. *Publ. INACH Serie. Cientifica* **1**: 41-54.

Gray, N.F., Smith, R.I. L. 1984. The distribution of nematophagous fungi in the maritime Antarctic. *Mycopathologia* **85**: 81-92.

Harris, C.M. 2001. *Revision of management plans for Antarctic protected areas originally proposed by the United States of America and the United Kingdom: Field visit report.* Internal report for the National Science Foundation, US, and the Foreign and Commonwealth Office, UK. Environmental Research and Assessment, Cambridge.

Hansom, J.D. 1979. Radiocarbon dating of a raised beach at 10 m in the South Shetland Islands. *British Antarctic Survey Bulletin* **49**: 287-288.

Hathway, B. 1997. Non-marine sedimentation in an Early Cretaceous extensional continental-margin arc, Byers Peninsula, Livingston Island, South Shetland Islands. *Journal of Sedimentary Research* **67**: 686-697.

Hathway, B., Lomas, S.A. 1998. The Upper Jurassic-Lower cretaceous Byers Group, South Shetland Islands, Antarctica: revised stratigraphy and regional correlations. *Cretaceous Research* **19**: 43-67.

Hernandez, P.J., Azcarate, V. 1971. Estudio paleobotanico preliminar sobre restos de una tafoflora de la Peninsula Byers (Cerro Negro), Isla Livingston, Islas Shetland del Sur, Antartica. *Publ. INACH Serie. Cientifica* **2**: 15-50.

Hjort, C., Ingólfsson, O., Björck, S. 1992. The last major deglaciation in the Antarctic Peninsula region - a review of recent Swedish Quaternary research. In: Y. Yoshida *et al*. (eds.) *Recent Progress in Antarctic Science*. Terra Scientific Publishing Company (TERRAPUB), Tokyo: 741-743.

Hjort, C., Björck, S., Ingólfsson, Ó., Möller, P. 1998. Holocene deglaciation and climate history of the northern Antarctic Peninsula region: a discussion of correlations between the Southern and Northern Hemispheres. *Annals of Glaciology* **27**: 110-112.

Hodgson, D.A., Dyson, C.L., Jones, V.J., Smellie, J.L. 1998. Tephra analysis of sediments from Midge Lake (South Shetland Islands) and Sombre Lake (South Orkney Islands), Antarctica. *Antarctic Science* **10**: 13-20.

John, B.S., Sugden, D.E. 1971. Raised marine features and phases of glaciation in the South Shetland Islands. *British Antarctic Survey Bulletin* **24**: 45-111.

Jones, V.J., Juggins, S., Ellis-Evans, J.C. 1993. The relationship between water chemistry and surface sediment diatom assemblages in maritime Antarctic lakes. *Antarctic Science* **5**: 339-48.

Kelly, S.R.A. 1995. New Trigonioid bivalves from the Early Jurassic to Earliest Cretaceous of the Antarctic Peninsula region: systematics and austral paleobiogeography. *Journal of Paleontology* **69**: 66-84.

Lindsay, D.C. 1971. Vegetation of the South Shetland Islands. *British Antarctic Survey Bulletin* **25**: 59-83.

López-Bueno, A., Tamames, J. Velazquez, D., Moya, A., Quesada, A., Alcami, A. 2009. Viral Metagenome of an Antarctic lake: high diversity and seasonal variations. *Science* **326**: 858-861.

Lopez-Martinez, J., Serrano, E., Martinez de Pison, E. 1996. Geomorphological features of the drainage system. In: López-Martínez, J., Thomson, M. R. A., Thomson, J.W. (eds.) *Geomorphological map of Byers Peninsula, Livingston Island*. BAS GEOMAP Series Sheet 5-A, 15-19. British Antarctic Survey, Cambridge.

Lopez-Martínez, J., Martínez de Pisón, E., Serrano, E., Arche, A. 1996 *Geomorphological map of Byers Peninsula, Livingston Island*. BAS GEOMAP Series, Sheet 5-A, Scale 1:25 000. Cambridge, British Antarctic Survey,.

Martínez De Pisón, E., Serrano, E., Arche, A., Lopez-Martínez, J. 1996. Glacial geomorphology. In: López-Martínez, J., Thomson, M. R. A., Thomson, J.W. (eds.) *Geomorphological map of Byers Peninsula, Livingston Island*. BAS GEOMAP Series Sheet 5-A, 23-27. British Antarctic Survey, Cambridge.

Pankhurst, R.J., Weaver, S.D., Brook, M., Saunders, A.D. 1979. K-Ar chronology of Byers Peninsula, Livingston Island, South Shetland Islands. *British Antarctic Survey Bulletin* **49**: 277-282.

Petz, W., Valbonesi, A., Schiftner, U., Quesada, A., Ellis-Evans, C.J. 2007. Ciliate biogeography in Antarctic and Arctic freshwater ecosystems: endemism or global distribution of species? *FEMS Microbiology Ecology* **59**: 396-408.

Quesada, A., Fernández Valiente, E., Hawes, I., Howard.Williams, C. 2008. Benthic primary production in polar lakes and rivers. In: Vincent, W., Leybourn-Parry J. (eds). *Polar Lakes and Rivers – Arctic and Antarctic Aquatic Ecosystems.* Springer. pp 179-196.

Quesada, A., Camacho, A. Rochera, C., Velazquez, D. 2009. Byers Peninsula: a reference site for coastal, terrestrial and limnetic ecosystems studies in maritime Antarctica. *Polar Science* **3**: 181-187.

Richard, K.J., Convey, P., Block, W. 1994. The terrestrial arthropod fauna of the Byers Peninsula, Livingston Island, South Shetland Islands. *Polar Biology* **14**: 371-79.

Rodríguez, P., Rico, E. 2008. A new freshwater oligochaete species (Clitellata: Enchytraeidae) from Livingston Island, Antarctica. *Polar Biology* **31**: 1267-1279.

SGE, WAM and BAS. 1993. *Byers Peninsula, Livingston Island*. Topographic map, Scale 1:25 000. Cartografia Antartica. Madrid, Servicio Geografia del Ejercito.

Serrano, E., Martínez De Pisón, E., Lopez-Martínez, J. 1996. Periglacial and nival landforms and deposits. In: López-Martínez, J., Thomson, M. R. A., Thomson, J.W. (eds.) *Geomorphological map of Byers Peninsula, Livingston Island*. BAS GEOMAP Series Sheet 5-A, 28-34. British Antarctic Survey, Cambridge.

Smellie J.L., Davies, R.E.S., Thomson, M.R.A. 1980. Geology of a Mesozoic intra-arc sequence on Byers Peninsula, Livingston Island, South Shetland Islands. *British Antarctic Survey Bulletin* **50**: 55-76.

Smith, R.I.L., Simpson, H.W. 1987. Early Nineteeth Century sealers' refuges on Livingston Island, South Shetland Islands. *British Antarctic Survey Bulletin* **74**: 49-72.

Starý, J., Block, W. 1998. Distribution and biogeography of oribatid mites (Acari: Oribatida) in Antarctica, the sub-Antarctic and nearby land areas. *Journal of Natural History* **32**: 861-94.

Sugden, D.E., John, B.S. 1973. The ages of glacier fluctuations in the South Shetland Islands, Antarctica. In: van Zinderen Bakker, E.M. (ed.) *Paleoecology of Africa and of the surrounding islands and Antarctica* . Balkema, Cape Town, pp. 141-159.

Tejedo, P., Justel, A., Benayas, J., Rico, E., Convey, P., Quesada, A. 2009. Soil trampling in an Antarctic Specially Protected Area: tools to assess levels of human impact. *Antarctic Science* **21**: 229-236.

Thom, G. 1978. Disruption of bedrock by the growth and collapse of ice lenses. *Journal of Glaciology* **20**: 571-75.

Thomson, M.R.A., López-Martínez, J. 1996. Introduction. In: López-Martínez, J., Thomson, M. R. A., Thomson, J.W. (eds.) *Geomorphological map of Byers Peninsula, Livingston Island*. BAS GEOMAP Series Sheet 5-A, 1-4. British Antarctic Survey, Cambridge.

Toro, M., Camacho, A., Rochera, C., Rico, E., Bañón, M., Fernández, E., Marco, E., Avendaño, C., Ariosa, Y., Quesada, A. 2007. Limnology of freshwater ecosystems of Byers Peninsula (Livingston Island, South Shetland Islands, Antarctica. *Polar Biology* **30**: 635-649.

Torres, D., Cattan, P., Yanez, J. 1981. Post-breeding preferences of the Southern Elephant seal *Mirounga leonina* in Livingston Island (South Shetlands). *Publ. INACH Serie. Cientifica* **27**: 13-18.

Torres, D., Jorquera, D. 1994. Marine debris analysis collected at cape Shirreff, Livingston Island, South Shetland, Antarctica. *Ser. Cient. INACH* **44**: 81-86.

Usher, M.B., Edwards, M. 1986. The selection of conservation areas in Antarctica: an example using the arthropod fauna of Antarctic islands. *Environmental Conservation* **13**: 115-22.

Van der Vijver, J., Agius, T., Gibson, J., Quesada, A. 2009. An unusual spine-bearing Pinnularia species from the Antarctic Livingston Island. *Diatom Research* **24**: 431-441.

White, M.G. Preliminary report on field studies in the South Shetland Islands 1965/66. Unpublished field report in BAS Archives AD6/2H1966/N6.

Woehler, E.J. (Ed.) 1993. *The distribution and abundance of Antarctic and sub-Antarctic penguins*. SCAR, Cambridge.

Zidarova, E., Van de Vijver, B., Quesada, A., de Haan, M. 2010. Revision of the genus Hantzschia (Bacillariophyceae) on Livingston Island (South Shetland Islands, Southern Atlantic Ocean). *Plant Ecology and Evolution*. In press.

Annex 1

Supporting information

CLIMATE

No extended meteorological records are available for Byers Peninsula before 2001, but the climate is expected to be similar to that at Base Juan Carlos I, Hurd Peninsula (recorded since 1988). Conditions there indicate a mean annual temperature of below 0 ºC, with temperatures less than 0 ºC for at least several months each summer and a relatively high precipitation rate estimated at about 800 mm yr^{-1}, much of which falls as rain in summer (Ellis-Evans 1996). The peninsula is snow-covered for much of the year, but is usually completely snow-free by the end of the summer. The peninsula is exposed to weather from the Drake Passage in the north and northwest, the directions from which winds prevail, and Bransfield Strait to the south. The climate is polar maritime, with a permanently high relative humidity (about 90%), cloud covered skies for most of the time, frequent fogs and regular precipitation events. Mean temperature in summer is 1.1 º C, but occasionally can be higher than 5 ºC. Exceptionally summer temperature has reached 9 ºC. Minimum average temperature is close to 0 ºC. In winter, temperatures can be lower than -26 ºC, although the average value is -6 ºC and maximum temperatures in winter can be close to 0 ºC. Mean radiation in summer is 14,000 KJ m^{-2}, reaching 30,000 KJ m^{-2} on sunny days close to the solstice. Winds are high and average speed is 24 km h^{-1}, with frequent storms with winds over 140 Km h^{-1}. The predominant winds are from SW and NE.

GEOLOGY

The bedrock of Byers Peninsula is composed of Upper Jurassic to Lower Cretaceous marine sedimentary, volcanic and volcaniclastic rocks, intruded by igneous bodies (see Smellie *et al* 1980; Crame *et al* 1993, Hathway and Lomas 1998). The rocks represent part of a Mesozoic-Cenozoic magmatic arc complex which is exposed throughout the whole of the Antarctic Peninsula region, although most extensively on the Byers Peninsula (Hathway and Lomas 1998). The elevated interior region of the eastern half of the peninsula – surrounded to the north and south by Holocene beach deposits – is dominated by Lower Cretaceous non-marine tuffs, volcanic breccias, conglomerates, sandstones and minor mudstones, with intrusions in several places by volcanic plugs and sills. The western half of the peninsula, and extending NW half-way along Ray Promontory, is predominantly Upper Jurassic-Lower Cretaceous marine mudstones, with sandstones and conglomerates, with frequent intrusions of volcanic sills, plugs and other igneous bodies. The NW half of Ray Promontory comprises mainly volcanic breccias of the same age. Mudstones, sandstones, conglomerates and pyroclastic rocks are the most common lithologies found on the peninsula. Expanses of Holocene beach gravels and alluvium are found in coastal areas, particularly on South Beaches and the eastern half of Robbery Beaches, with less-extensive deposits on President Beaches.

The Area is of high geological value because “the sedimentary and igneous rocks exposed at Byers Peninsula constitute the most complete record of the Jurassic-Early Cretaceous period in the northern part of the Pacific flank of the magmatic arc complex, and they have proved a key succession for the study of marine molluscan faunas (e.g. Crame 1984, 1995, Crame and Kelly 1995) and non-marine floras (e.g. Hernandez and Azcárte 1971, Philippe *et al* 1995)” (Hathway and Lomas 1998).

GEOMORPHOLOGY AND SOILS

Much of the terrain consists of lithosols, essentially a layer of shattered rock, with permafrost widespread below an active layer of 30-70 cm depth (Thom 1978, Ellis-Evans 1996, Serrano *et al* 1996). Stone fields (consisting of silty fines with dispersed boulders and surficial clasts), gelifluction lobes, polygonal ground (both in flooded and dry areas), stone stripes and circles and other periglacial landforms dominate the surface morphology of the upper platforms where bedrock outcrop is absent (Serrano at al 1996). Debris and mud-flows are observed in several localities. Beneath some of the moss and grass communities there is a 10-20 cm deep layer of organic matter although, because vegetation is sparse over most of Byers Peninsula, there are no deep accumulations of peat (Bonner and Smith 1985). Ornithogenic soils are present especially in the Devils Point vicinity and on a number of knolls along President Beaches (Ellis-Evans 1996).

Parts of the interior of the peninsula have been shaped by coastal processes with a series of raised beaches ranging from 3 to 54 m in altitude, some of which are over 1 km wide. A radiocarbon date for the highest beach deposits suggests that Byers Peninsula was largely free of permanent ice by 9700 yr B.P., while the lowest beach deposits are dated at 300 yr B.P (John and Sugden 1971, Sugden and John 1973). Lake sediment analyses, however, suggest a more recent general deglaciation of central Byers Peninsula of around 4000-5000 yr B.P. and radiocarbon dates in the locality need to be interpreted cautiously (Björck *et al* 1991a, b). In several places sub-fossil whalebones are embedded in the raised beaches, occasionally as almost entire skeletons. Radiocarbon dates of skeletal material from about 10 m a.s.l. on South Beaches suggest an age of between 2000 and 2400 yr B.P. (Hansom 1979). Pre-Holocene surfaces of Byers Peninsula exhibit clear evidence of a glacial landscape, despite the gentle landforms. Today only three small residual glaciers (comprising less then 0.5 km^2) remain on Ray Promontory. The pre-existing glacially modified landforms, have been subsequently overprinted by fluvial and periglacial processes, and moraines and other glacial deposits are scarce (Martinez de Pison *et al* 1996).

STREAMS AND LAKES

Byers Peninsula is perhaps the most significant limnological site in the South Shetland Islands/Antarctic Peninsula region, with over 60 lakes, numerous freshwater pools (differentiated from lakes in that they freeze to the bottom in winter) and a dense and varied stream network. The gentle terrain favours water retention and waterlogged soils are common in the summer. The water capacity of the thin soils is limited, however, and many of the channels are frequently dry, with flow often intermittent except during periods of substantial snow melt or where they drain glaciers (Lopez-Martinez *et al* 1996). Most of the streams drain seasonal snowfields and are often no more than 5-10 cm in depth (Ellis-Evans 1996) although snow accumulation in some narrow gorges can reach over 2 m height, and result in ice dams blocking the lake outlet. The larger streams are up to 4.5 km in length, up to 20 m in width and 30-50 cm in depth in the lower reaches during periods of flow. Streams that drain to the west often have sizeable gorges (Lopez-Martinez *et al* 1996) and gullies up to 30 m in depth have been cut into the uppermost, and largest, of the raised marine platforms (Ellis-Evans 1996). Above the Holocene raised beaches the valleys are gentle, with widths of up to several hundred metres.

Lakes are especially abundant on the higher platforms (i.e. at the heads of basins) and on the Holocene raised beaches near the coast. Midge Lake is the largest at 587 × 112 m, and deepest with a maximum depth of 9.0 m. The inland lakes are all nutrient-poor and highly transparent, with extensive sediments in deeper water overlain by a dense aquatic moss carpet [*Drepanocladus longifolius (=D. aduncus*)]. In some lakes, such as Chester Cone Lake about 500 m to the south of Midge Lake, or Limnopolar lake, stands of aquatic moss are found growing at one to several metres in depth and cover most of the lake bottom, which is the habitat for *Parochlus* larvae (Bonner and Smith 1985). Large masses of this moss are sometimes washed up along parts of the shoreline. The lakes are generally frozen to a depth of 1.0 - 1.5 m for 9 - 11 months of the year and overlain by snow, although surfaces of some of the higher lakes remain frozen year-round (Ellis-Evans 1996, Lopez-Martinez *et al* 1996). On the upper levels of the central plateau many small, shallow, slow-flowing streams flow between lakes and drain onto large flat areas of saturated lithosol covered with thick cyanobacterial mats of *Phormidium* sp. These mats are more extensive than in any other maritime Antarctic site thus far described and reflect the unique geomorphology and relatively high annual precipitation of the Area. With spring melt there is considerable flush through most lakes, but outflow from many lakes may cease late in the season as seasonal snowmelt decreases. Most lakes contain some crustaceans such as the copepods *Boeckella poppei* and the fairy shrimp *Branchinecta gainii*. Some of the streams also contain substantial growths of cyanobacterial and green filamentous algae, along with diatoms and copepods. A number of relatively saline lakes of lagoonal origin occur close to the shore, particularly on President Beaches. Where these are used as southern elephant seal (*Mirounga leonina*) wallows these lakes have been highly organically enriched. Those coastal shallow lakes and pools located behind the first raised beach often have abundant algal mats and crustaceans, including the copepods *B. poppei* and *Parabroteas sorsi*, and occasionally the fairy shrimp *Br. gainii*. Some of these water bodies have high biological diversity, with newly described species of diatoms (van der Vijver 2010), oligochaete (Rodriguez and Rico, 2009) and ciliate protozoa (Petz et al 2008).

VEGETATION

Although much of Byers Peninsula lacks abundant vegetation, especially inland (see Lindsay 1971), the sparse communities contain a diverse flora, with at least 56 lichen species, 29 mosses, 5 hepatics and 2 phanerogams having been identified as present within the Area. Numerous unidentified lichens and mosses have also been collected. This suggests the Area contains one of the most diverse representations of terrestrial flora known in the maritime Antarctic. A number of the species are rare in this part of the maritime Antarctic. For example, of the bryophytes, *Anthelia juratzkana*, *Brachythecium austroglareosum*, *Chorisodontium aciphyllum, Ditrichum hyalinum, Herzogobryum teres*, *Hypnum revolutum*, *Notoligotrichum trichodon, Pachyglossa dissitifolia, Platydictya jungermannioides, Sanionia* cf. *plicata*, *Schistidium occultum, Syntrichia filaris* and *Syntrichia saxicola* are considered rare. For *A. juratzkana*, *D. hyalinum*, *N. trichodon* and *S. plicata*, their furthest-south record is on Byers Peninsula. Of the lichen flora, *Himantormia lugubris, Ochrolechia parella*, *Peltigera didactyla* and *Pleopsidium chlorophanum* are considered rare.

Vegetation development is much greater on the south coast than on the north. Commonly found on the higher, drier raised beaches in the south is an open community dominated by abundant *Polytrichastrum alpinum* (=*Polytrichum alpinum*), *Polytrichum piliferum* (=*Polytrichum antarcticum*), *P. juniperinum*, *Ceratodon purpureus*, and the moss *Pohlia nutans* and several crustose lichens are frequent. Some large stands of mosses occur near President and South Beaches, where extensive snowdrifts often accumulate at the base of slopes rising behind the raised beaches, providing an ample source of melt water in the summer. These moss stands are dominated mainly by *Sanionia uncinata* (=*Drepanocladus uncinatus*), which locally forms continuous carpets of several hectares. The vegetation composition is more diverse than on the higher, drier areas. Inland, wet valley floors have stands of *Brachythecium austro-salebrosum*, *Campylium polygamum, Sanionia uncinata*, *Warnstorfia laculosa* (=*Calliergidium austro-stramineum*), and *W. sarmentosa* (=*Calliergon sarmentosum*). In contrast, moss carpets are almost non-existent within 250 m of the northern coast, replaced by scant growth of *Sanionia* in hollows between raised beaches of up to 12 m in altitude. Lichens, principally of the genera *Acarospora, Buellia, Caloplaca, Verrucaria* and *Xanthoria*, are present on the lower (2-5 m) raised beach crests, with *Sphaerophorus, Stereocaulon* and *Usnea* becoming the more dominant lichens with increasing altitude (Lindsay 1971).

On better drained ash slopes *Bryum* spp., *Dicranoweisia* spp., *Ditrichum* spp., *Pohlia* spp., *Schistidium* spp., and *Tortula* spp. are common as isolated cushions and turves with various liverworts, lichens (notably the pink *Placopsis contortuplicata* and black foliose *Leptogium puberulum*), and the cyanobacterium *Nostoc commune*. *P. contortuplicata* occurs in inland and upland habitats lacking in nitrogen, and is typical of substrata with some degree of disturbance such as solifluction; it is often the only plant to colonise the small rock fragments of stone stripes and frost-heave polygons (Lindsay 1971). It is usually found growing alone, though rarely with species of *Andreaea* and *Usnea*. *N. commune* covers extensive saturated areas on level or gently sloping, gravelly boulder clay from altitudes of between 60-150 m, forming discrete rosettes of about 5 cm in diameter 10-20 cm apart (Lindsay 1971). Scattered, almost spherical, cushions of *Andreaea, Dicranoweisia,* and *Ditrichum* are found on the driest soils. In wet, bird- and seal-influenced areas the green foliose alga *Prasiola crispa* is sometimes abundant.

Rock surfaces on Byers Peninsula are mostly friable, but locally colonised by lichens, especially near the coast. Volcanic plugs are composed of harder, more stable rock and are densely covered by lichens and occasional mosses. Usnea Plug is remarkable for its luxuriant growth of *Himantormia lugubris* and *Usnea aurantiaco-atra* (=*U. fasciata*). More generally, *H. lugubris* and *U. aurantiaco-atra* are the dominant lichen species on inland exposed montane surfaces, growing with the moss *Andreaea gainii* over much of the exposed rock with up to 80% cover of the substratum (Lindsay 1971). In sheltered pockets harbouring small accumulations of mineral soil, the liverworts *Barbilophozia hatcheri* and *Cephaloziella varians* (= *C. exiliflora*) are often found, but more frequently intermixed with cushions of *Bryum, Ceratodon, Dicranoweisia, Pohlia, Sanionia, Schistidium,* and *Tortula.* *Sanionia* and *Warnstorfia* form small stands, possibly correlated with the absence of large snow patches and associated melt streams. *Polytrichastrum alpinum* forms small inconspicuous cushions in hollows, but it may merge with *Andreaea gainii* cushions in favourable situations (Lindsay 1971).

Crustose lichens are mainly species of *Buellia, Lecanora, Lecedella, Lecidea, Placopsis* and *Rhizocarpon* growing on rock, with species of *Cladonia* and *Stereocaulon* growing on mosses, particularly *Andreaea* (Lindsay 1971). On the south coast moss carpets are commonly colonised by epiphytic lichens, such as *Leptogium puberulum, Peltigera rufescens*, *Psoroma* spp., together with *Coclocaulon aculeata* and *C. epiphorella*. On sea cliffs *Caloplaca* and *Verrucaria* spp. dominate on lower surfaces exposed to salt spray up to about 5 m, with nitrophilous species, such as *Caloplaca regalis*, *Haematomma erythromma*,and

Xanthoria elegans often dominant at higher altitudes where seabirds are frequently nesting. Elsewhere on dry cliff surfaces a *Ramalina terebrata* - crustose lichen community is common. A variety of ornithocoprophilous lichens, such as *Catillaria corymbosa, Lecania brialmontii,* and species of *Buellia, Haematomma, Lecanora,* and *Physcia* occur on rocks near concentrations of breeding birds, along with the foliose lichens *Mastodia tessellata, Xanthoria elegans* and *X. candelaria* which are usually dominant on dry boulders.

Antarctic hairgrass (*Deschampsia antarctica*) is common in several localities, mainly on the south coast, and occasionally forms closed swards (e.g. at Sealer Hill); Antarctic pearlwort (*Colobanthus quitensis*) is sometimes associated. Both plants are quite abundant in southern gullies with a steep north-facing slope, forming large, occasionally pure stands with thick carpets of *Brachythecium* and *Sanionia*, although they are rarely found above 50 m in altitude (Lindsay 1971). An open community of predominantly *Deschampsia* and *Polytrichum piliferum* extends for several kilometres on the sandy, dry, flat raised beaches on South Beaches. A unique growth-form of the grass, forming isolated mounds 25 cm high and up to 2 m across, occurs on the beach near Sealer Hill. *Deschampsia* has been reported at only one locality on the north coast (Lair Point), where it forms small stunted tufts (Lindsay 1971).

INVERTEBRATES

The microinvertebrate fauna on Byers Peninsula thus far described comprises 25 taxa (Usher and Edwards 1986, Richard *et al* 1994, Block and Stary 1996, Convey *et al* 1996, Rodriguez and Rico, 2008): six Collembola (*Cryptopygus antarcticus, Cryptopygus badasa, Friesea grisea, Friesea woyciechowskii, Isotoma* (*Folsomotoma*) *octooculata* (=*Parisotoma octooculata*) and *Tullbergia mixta*; one mesostigmatid mite (*Gamasellus racovitzai*), five cryptostigmatid mites (*Alaskozetes antarcticus, Edwardzetes dentifer, Globoppia loxolineata* (=*Oppia loxolineata*), *Halozetes belgicae* and *Magellozetes antarcticus*); nine prostigmatid mites (*Bakerdania antarcticus, Ereynetes macquariensis, Eupodes minutus, Eupodes parvus grahamensis, Nanorchestes berryi, Nanorchestes nivalis, Pretriophtydeus tilbrooki, Rhagidia gerlachei, Rhagidia leechi,* and *Stereotydeus villosus*); two Dipterans (*Belgica antarctica* and *Parochlus steinenii*), and two oligochaetes (*Lumbricillus healyae* and *Lumbricillus sp*.).

Larvae of the wingless midge *Belgica antarctica* occur in limited numbers in moist moss, especially carpets of *Sanionia*, although it is of very restricted distribution on Byers Peninsula (found especially near Cerro Negro) and may be near its northern geographical limit. The winged midge *Parochlus steinenii* and its larvae inhabit the margins of inland lakes and pools, notably Midge Lake and another near Usnea Plug, and are also found amongst the stones of many stream beds (Bonner and Smith 1985, Richard *et al* 1994, Ellis-Evans pers comm 1999). During warm calm weather, swarms of adults may be seen above lake margins.

The diversity of the arthropod community described at Byers Peninsula is greater than at any other documented Antarctic site (Convey *et al* 1996). Various studies (Usher and Edwards 1986, Richard *et al* 1994, Convey *et al* 1996) have demonstrated that the arthropod population composition on Byers Peninsula varies significantly with habitat over a small area. *Tullbergia mixta* has been observed in relatively large numbers; it appears to be limited in Antarctic distribution to the South Shetland Islands (Usher and Edwards 1986). Locally, the greatest diversity is likely to be observed in communities dominated by moss cushions such as *Andreaea* spp. (Usher and Edwards 1986). Further sampling is required to establish populations and diversities with greater reliability. While further sampling at other sites may yet reveal the communities described at Byers Peninsula to be typical of similar habitats in the region, available data on the microfauna confirm the biological importance of the Area.

MICROORGANISMS

An analysis of soil samples collected from Byers Peninsula yielded several nematophagous fungi: in soil colonised by *Deschampsia* were found *Acrostalagmus goniodes*, *A. obovatus, Cephalosporium balanoides* and *Dactylaria gracilis,* while in *Colobanthus*-dominated soil was found *Cephalosporium balanoides* and *Dactylella gephyropaga* (Gray and Smith 1984). The basidiomycete *Omphalina antarctica* is often abundant on moist stands of the moss *Sanionia uncinata* (Bonner and Smith 1985).

Some of the water bodies have high microbial biodiversity including the largest viral genetic diversity found in Antarctic lakes (López-Bueno et al 2009)

BREEDING BIRDS

The avifauna of Byers Peninsula is diverse, although breeding colonies are generally not large. Two species of penguin, the chinstrap (*Pygoscelis antarctica*) and the gentoo (*P. papua*), breed in the Area.

Adélie penguins (*P. adeliae*) have not been observed to breed on Byers Peninsula or its offshore islets. In the South Shetlands Islands, Adélie penguins only breeds on King George Island where the populations are declining (Carlini et al. 2009).

The principal chinstrap penguin colony is at Devils Point, where a rough estimate of about 3000 pairs was made in 1987; a more accurate count made in 1965 indicated about 5300 pairs in four discrete colonies, of which almost 95% were nesting on Demon Island, 100 m to the south of Devils Point (Croxall and Kirkwood 1979; Woehler 1993). Two colonies of about 25 chinstrap penguin pairs surrounded by a colony of gentoo penguins can be found on the President Beaches close to Devils Point. Small chinstrap penguin colonies have been reported on the northern coast, e.g. on Robbery Beaches (50 pairs in 1958; Woehler 1993), but no breeding pairs were reported there in a 1987 survey. In other locations, Lair Point contained 156 pairs in 1966, declining to 25 pairs in 1987 (Woehler 1993). In a recent visit to the area (January 2009) 20 pairs were counted (Barbosa pers.com).

Gentoo penguins breed at several colonies on Devils Point, with approximately 750 pairs recorded in 1965 (Croxall and Kirkwood 1979, Woehler 1993). Currently three colonies of about 3000 pairs in total can be found (Barbosa pers.com). On the northern coast, a rookery of three colonies with 900 pairs in total is located in Robbery Beaches (Woehler 1993). In a visit to Lair Point in January 2009, about 1200 pairs were counted. Woehler (1993) gives no data on gentoo penguins at this location.

Recent estimations of population size for some species of flying birds were obtained from a survey conducted in December 2008 and January 2009 (Gil-Delgado et al. 2010). The Antarctic tern (*Sterna vittata*) population was estimated at 1873 breeding pairs. Two hundred and thirty eight pairs of southern giant petrels *(Macronectes giganticus)* and 15 pairs of brown skua (*Catharacta lonnbergi*) nest locally. A detailed survey of other breeding birds was conducted in 1965 (White 1965). The most populous breeding species recorded then, with approximately 1760 pairs, was the Antarctic tern (*Sterna vittata*), followed by 1315 pairs of Wilson's storm petrels (*Oceanites oceanicus*), approximately 570 pairs of cape petrels (*Daption capense*), 449 pairs of kelp gulls (*Larus dominicanus*), 216 pairs of southern giant petrels, 95 pairs of black-bellied storm petrels (*Fregetta tropica*), 47 pairs of blue-eyed cormorants (*Phalacrocorax atriceps*) (including those on nearshore islets), 39 pairs of brown skuas, and 3 pairs of sheathbills (*Chionis alba*). In addition, prions (*Pachytilla* sp.) and snow petrels (*Pagodroma nivea*) have been seen on the peninsula but their breeding presence has not been confirmed. The census of burrowing and scree-nesting birds is considered an underestimate (White pers. comm. 1999). The majority of the birds nest in close proximity to the coast, principally in the west and south.

Recently some vagrant waders, probably white-rumped sandpipers (*Calidris fuscicollis*) have been seen frequently foraging in some streams in the southern beaches (Quesada pers. comm. 2009).

BREEDING MAMMALS

Large groups of southern elephant seals (*Mirounga leonina*) breed on the Byers Peninsula coast, with a total of over 2500 individuals reported on South Beaches (Torres *et al*. 1981), which is one of the largest populations of this species recorded in the South Shetland Islands. A estimation made in 2008-2009 showed a population ranging from 4700 to 6300 individuals (Gil-Delgado et al. 2010). Large numbers haul out in wallows and along beaches in summer. Weddell (*Leptonychotes weddellii*), crabeater (*Lobodon carcinophagous*) and leopard (*Hydrurga leptonyx*) seals may be seen around the shorelines. Antarctic fur seals (*Arctocephalus gazella*) were once very abundant on Byers Peninsula (see below), but have not substantially recolonised the Area in high numbers in spite of the recent rapid population expansion in other parts of the maritime Antarctic.

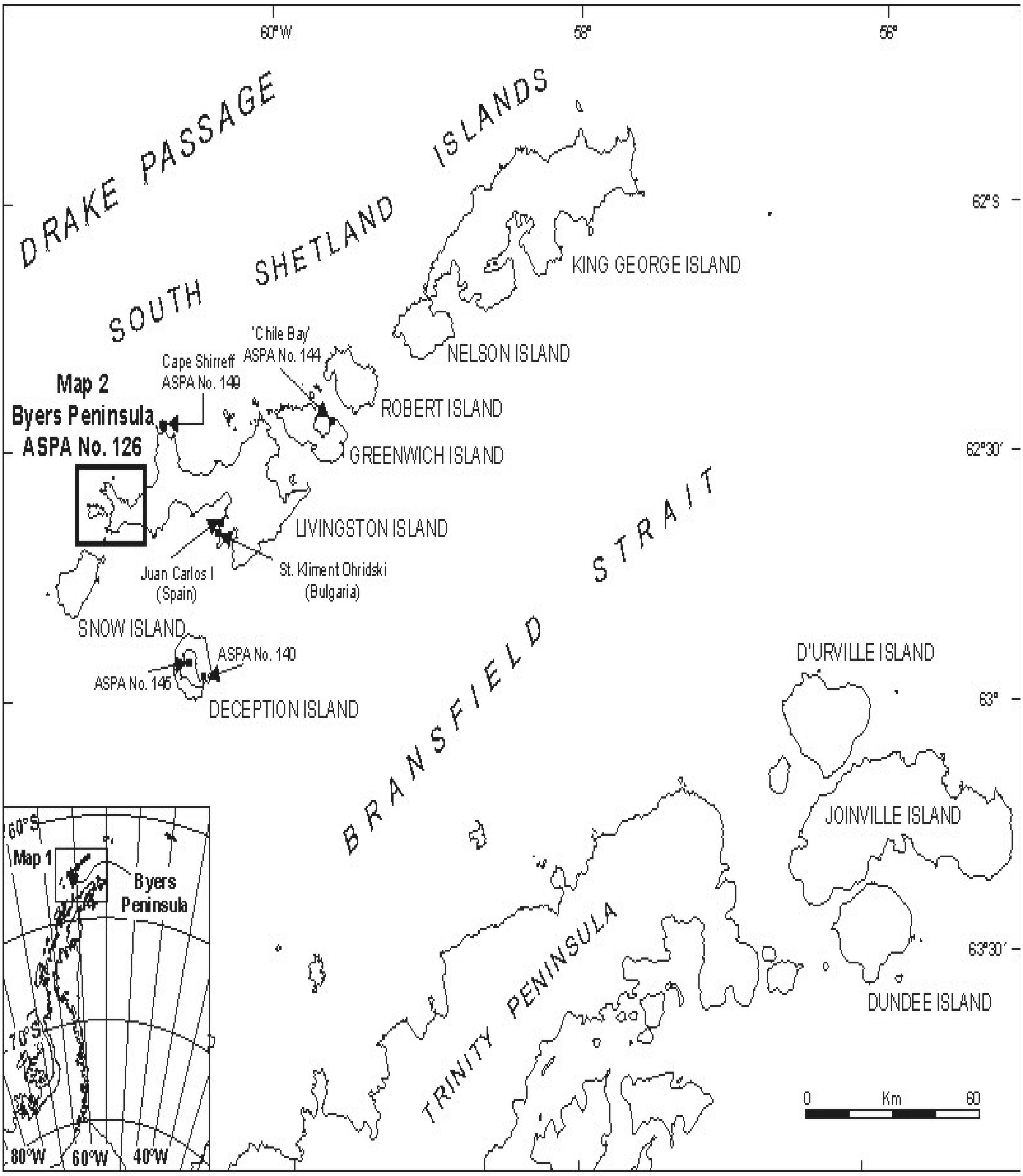
HISTORICAL FEATURES

Following discovery of the South Shetland Islands in 1819, intensive sealing at Byers Peninsula between 1820 and 1824 exterminated almost all local Antarctic fur seals and southern elephant seals (Smith and Simpson 1987). During this period there was a summer population of up to 200 American and British sealers living ashore in dry-stone refuges and caves around Byers Peninsula (Smith and Simpson 1987). Evidence of their occupation remains in their many refuges, some of which still contain artefacts (clothing, implements, structural materials, etc.). Several sealing vessels were wrecked near Byers Peninsula and timbers from these ships may be found along the shores. Byers Peninsula has the greatest concentration of early 19th Century sealers' refuges and associated relics in the Antarctic and these are vulnerable to disturbance and/or removal.

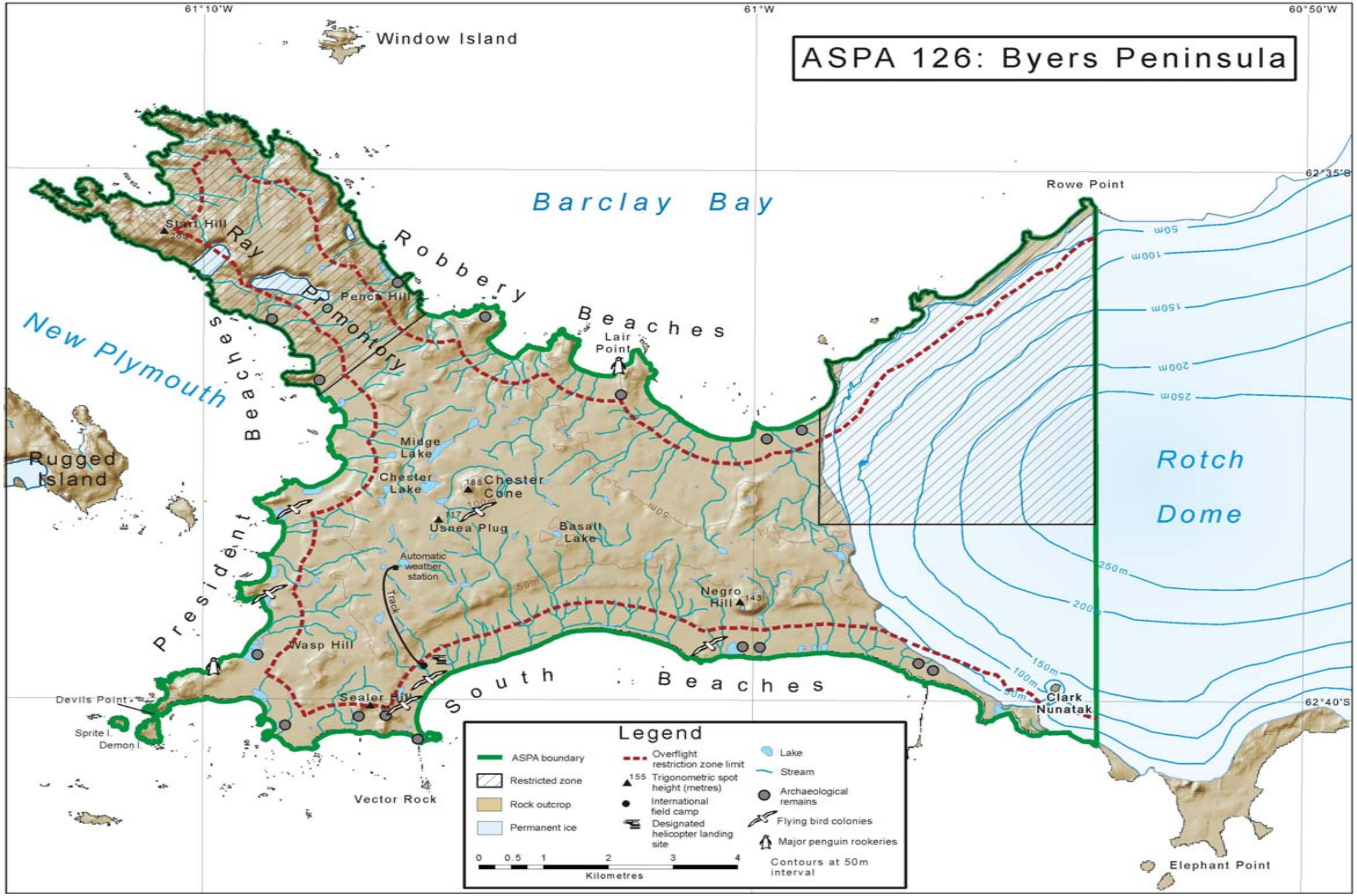
Elephant seal numbers, and to some extent fur seal numbers, recovered after 1860, but were again decimated by a second sealing cycle extending to the first decade of the twentieth century.

HUMAN ACTIVITIES/IMPACTS

The modern era of human activity at Byers Peninsula has been largely confined to science. The impacts of these activities have not been described, but are believed to be minor and limited to items such as campsites, footprints, markers of various kinds, sea-borne litter washed onto beaches (e.g. from fishing vessels) and from human wastes and scientific sampling. Several wooden stake markers and a plastic fishing float were observed in the southwest of the Area in a brief visit made in February 2001 (Harris 2001). In summer 2009-2010, a beach litter survey was undertaken (Rodriguez-Pertierra pers. comm.). The highest proportion of litter on beaches (averaged over beach length) was found in Robbery Beach (64%) followed by President Beach (28%) and beaches to the southwest of the Area (8%). This is likely to be related to their exposure to the Drake Passage (Torres and Jorquera, 1994). The majority of the litter found on the three beaches was wood (78% by number of items) and plastic (19%) whereas metal, glass and cloth were found more rarely (less than 1%). Several pieces of timber were found, some of them quite large (several meters in length). The plastic items were highly diverse, with bottles, ropes and tape the most numerous items. Floats and glass bottles were also found on the beaches.



Map 1. Byers Peninsula, ASPA No. 126, Livingston Island, South Shetland Islands, location map.
Inset: location of Byers Peninsula on the Antarctic Peninsula



Map 2. ASPA 126: Byers Peninsula topographic map.

WP 59

Antarctic Treaty
Consultative Meeting XXXV
HOBART 2012

Tema del Programa:	CPA 7c
Presentado por:	Ecuador, España
Original:	Español
Enviado:	30/04/2012

Revisión de las directrices para sitios visitados: Isla Barrientos (Islas Aitcho)

Revisión de las Directrices para sitios visitados: Isla Barrientos (Islas Aitcho)

Documento de Trabajo presentado por Ecuador y España

Antecedentes

La Resolución 5 (2005) *Resolución para sitios que reciben visitantes (Estocolmo)* contenida en el informe final RCTA XXVIII recomendó "*la aplicación de las directrices para sitios aprobadas por la RCTA"*. Estas directrices fueron adoptadas sobre la base del informe RCTA XXVIII WP 031 presentado por Reino Unido, Australia y Estados Unidos. Uno de los sitios incluidos fue Isla Barrientos por situarse entre los quince primeros sitios de visita de la Península Antártica. Esta resolución también recomendaba que *"se establezcan procedimientos administrativos a fin de que el texto de las directrices para sitios pueda modificarse fácilmente con objeto de reflejar los rápidos cambios en las circunstancias ambientales".*

Este procedimiento de revisión fue establecido en la Resolución 1 (2010), la cual fue derogada posteriormente por la Resolución 4 (2011), actualmente vigente. En esta segunda Resolución se recomienda que "*toda propuesta de modificación de Directrices para sitios actuales sea analizada por el Comité para la Protección del Medio Ambiente, el que debe asesorar a la RCTA al respecto*".

El RCTA XXIX WP 002 *Cuestiones de política surgidas del examen in situ de las directrices para sitios que reciben visitantes en la Península Antártica (Edimburgo)* incluye como recomendación que "*se revisen las directrices para sitios si se produce algún cambio importante en el nivel y el tipo actuales de visitas a cualquiera de los sitios"*. Este documento también propone "*que el CPA considere opciones para el monitoreo sistemático y regular de los sitios"*.

La necesidad de revisar periódicamente estos instrumentos se recoge igualmente en el documento RCTA XXXIV WP 045 *Informe del grupo de contacto intersesional abierto sobre la revisión de los elementos ambientales de la Recomendación XVIII-1 (Buenos Aires)*. En este caso, se propone que *"el CPA decida en general que las directrices para sitios se revisen periódicamente por lo menos cada cinco años".*

Durante esta misma reunión, Ecuador presentó el documento RCTA XXXIV IP 0126 *Manejo turístico para la isla Barrientos (Buenos Aires)* en el que manifestó que *"en los últimos años, los Estados Consultivos, presentes con actividades antárticas han venido realizando esfuerzos de monitoreo y análisis del turismo que se desarrolla en los diferentes sitios de visita establecidos para la Antártida"* y que *"Ecuador desde el año 2007, ha planteado una serie de observaciones respecto de las dinámicas de turismo realizadas en la isla de Barrientos".* Asimismo manifestó el interés del país en *"realizar actividades de monitoreo turístico en la isla de Barrientos durante las temporadas de verano Antártico".*

Un equipo de investigación español se ha incorporado desde la campaña 2008-09 a la evaluación de las alteraciones debidas a la presencia de visitantes en Isla Barrientos, iniciando una estrecha colaboración con Ecuador desde la campaña 2011-12.

Actividades de seguimiento en la campaña 2011-12

En la última temporada de verano se ha continuado con las acciones de monitoreo iniciadas en años anteriores. Estos trabajos se realizaron entre el 12 de enero y 19 de febrero de 2012, e incluyeron:

- El monitoreo de las dinámicas de los visitantes: actividades y sitios de visita, formación y conducción de grupos de visitantes.
- El monitoreo de indicadores biofísicos en los senderos utilizados: anchura y amplitud de sendero, formación de trazados alternativos y pérdida de la cobertura vegetal.

Entre las observaciones más relevantes de la campaña de campo se encuentran:

- Durante el período de tiempo considerado, un total de trece embarcaciones fondearon frente a la playa sur y cuatro lo hicieron en el lado noreste de la isla. Destacar que esta primera zona de desembarco no se considera como tal en las actuales directrices para sitios visitados y que la zona identificada en este documento como área secundaria de desembarco no ha sido utilizada durante la temporada 2011-2012.

- Los lugares de visita utilizados por los tour operadores fueron: la pingüinera del extremo oriental de la isla, el sendero designado para cruzar el área vedada B (descrito en las directrices de visita), el sendero no oficial que cruza el centro de la isla, y el área de libre desplazamiento situada en el extremo occidental de Barrientos.
- Aproximadamente el 41% de las expediciones turísticas utilizaron el sendero no oficial que cruza el área vedada B (ver figura 2), mientras que el 24% recorrió el sendero designado en las directrices de visita. Un 34% permaneció en el área de playa de la pinguinera.
- El tamaño de los grupos de visitantes fue variable en cada caso, así como la presencia y supervisión por parte de los guías. Era habitual que se formaran grupos de visita para realizar el desplazamiento entre los sectores extremos de la isla. Sin embargo los grupos no siempre se formaron para llevar a cabo este desplazamiento ni tampoco cumplían, en la mayoría de los casos, con el requerimiento de la supervisión de un guía por cada grupo de 10 visitantes, un requisito especificado en las actuales directrices de sitio.
- El 65% de las expediciones turísticas monitoreadas visitaron la zona oeste de Barrientos. Las mayores acumulaciones de visitantes se dieron en la zona cercana a la laguna de deshielo, llegándose a documentar un grupo de 99 personas en el área de revolcadero de los elefantes marinos (*Mirounga leonina*).

Impactos detectados en los senderos

El 16 de enero de 2012 se realizó una primera medición de indicadores biofísicos en el sendero designado para cruzar el área vedada B y en el sendero no oficial que atraviesa el centro de la isla. El estudio se repitió el 16 de febrero de 2012, al final de la temporada. Se obtuvieron los siguientes resultados:

- En el caso del sendero designado para cruzar el área vedada B (Figura 1), al principio de la temporada turística no se observaron áreas con cobertura vegetal afectadas por el pisoteo de los visitantes ni la existencia de tramos o senderos alternativos. Las áreas de musgo circundantes al arroyo y aquellas cercanas a la parte rocosa del sendero costero se encontraban en buen estado.
- Al repetir el estudio al final de la temporada turística se observaron considerables daños y desprendimientos de la cobertura vegetal en varias zonas del trazado, especialmente en las áreas con praderas de musgos cercanas a la costa y al arroyo (Figura 2). Se documentaron tramos alternativos al sendero oficial con una longitud acumulada de 59 metros, los cuales discurrían principalmente sobre musgos. En algunos puntos se registraron anchuras superiores a los 6 metros, con abundantes huellas por pisoteo. A pesar de su menor uso, el daño sobre el sustrato y la capa vegetal en este sendero fueron severos debido a la existencia de un mayor contenido en agua en los propios suelos, lo que los convierte en más vulnerables frente al pisoteo.
- En el caso del sendero no oficial que cruza el centro de la isla, se aplicaron los mismos indicadores al principio de la temporada turística para obtener una información de referencia. En el análisis realizado al final de la campaña de trabajo, y a pesar de que la carga de visitantes fue mayor para este sendero, no se observaron daños significativos sobre el sustrato ni pérdida de cobertura vegetal. La menor presencia de agua y el tipo de sustrato hacen que este trazado sea menos vulnerable al pisoteo que el sendero designado en las directrices de visita.
- Aunque sí que se observó un ligero incremento de la anchura del trazado en ciertos puntos muy concretos, estos cambios no fueron tan severos como los observados en el sendero oficial. No se evidenció la formación de senderos o tramos alternativos.

Propuestas de modificación

Por todo lo anterior, las Partes proponen el ajuste de las actuales directrices para sitios visitados de Isla Barrientos incorporando los siguientes cambios:

- La revisión de los textos que se encuentra en el Anexo1.
- La sustitución del área de fondeo primaria propuesta actualmente (playa norte del extremo oriental de la isla) por la playa sur del extremo oriental de la isla.
- La sustitución del área de fondeo secundaria propuesta actualmente (playa norte del extremo occidental de la isla) por la playa norte del extremo oriental de la isla.
- La modificación de la ruta designada que cruza el área vedada B por motivos de recuperación de la capa vegetal próxima al sendero y bajo el principio de precaución. Se propone recuperar la antigua ruta que discurre por el centro de la isla y que conecta la playa sur del extremo oriental de Barrientos con el área de libre desplazamiento situada en el extremo occidental (Anexo 2).
- La incorporación de los tres últimos cambios en los mapas de las directrices para sitios visitados de Isla Barrientos.

Finalmente, quienes presentan este documento ponen a consideración del Tratado su disponibilidad para continuar con acciones de monitoreo durante los veranos antárticos con la finalidad de evaluar los resultados de las medidas de manejo propuestas y, si así lo decidieran las Partes, ampliar estas acciones de monitoreo a otros sitios de visita para lo cual hacen un llamado a los Países Miembros para formar parte de este esfuerzo.

Figura 1 – Mapa de senderos actuales de la isla Barrientos

Figura 2- Mapa de senderos alternativos formados en sendero que cruza el área vedada B

Figura 3 – Dossier fotográfico de observaciones en sendero que cruza el área vedada B

Figura 1 – Mapa de senderos actuales de la isla Barrientos

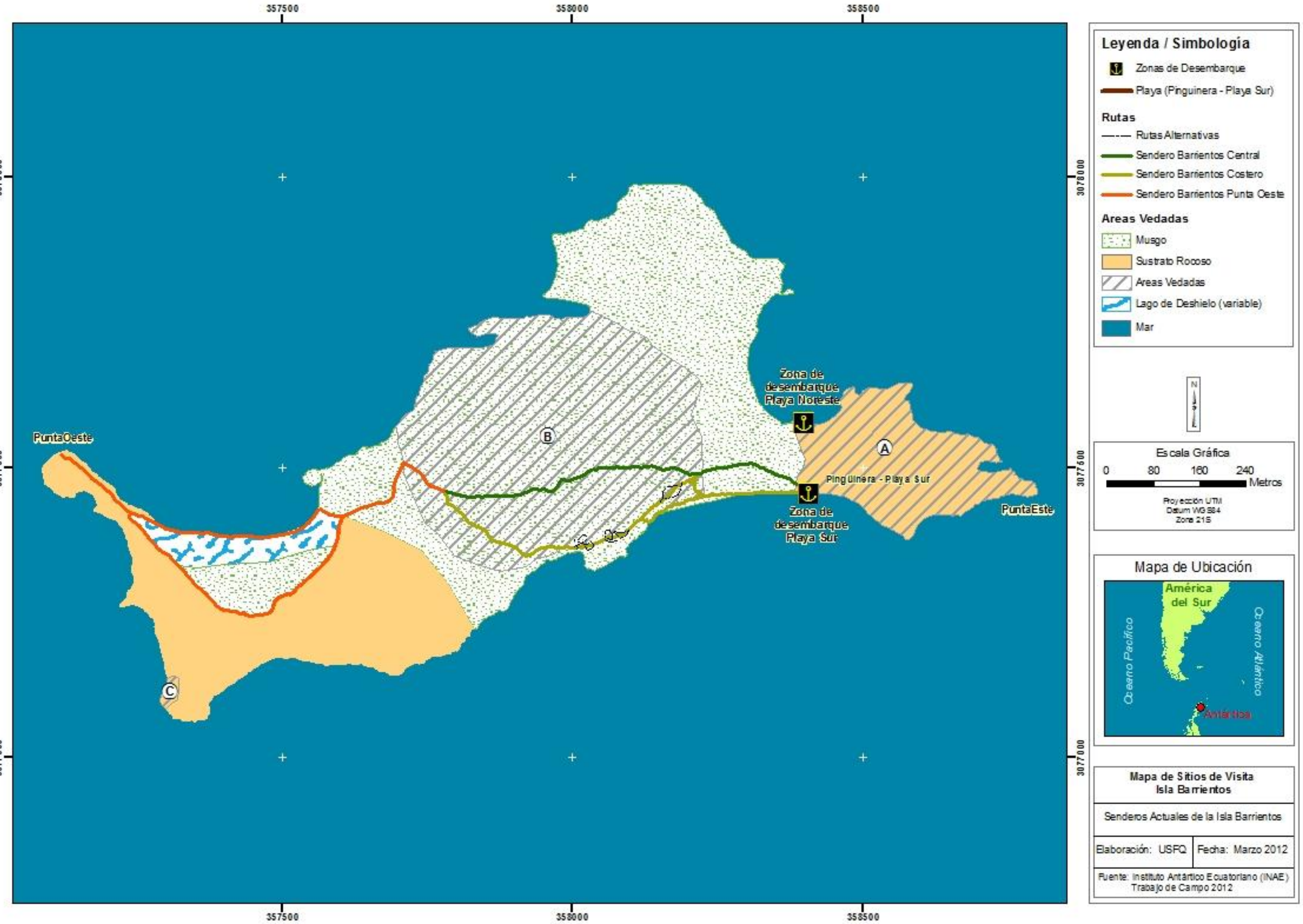


Figura 2- Mapa de senderos alternativos formados en sendero que cruza el área vedada B

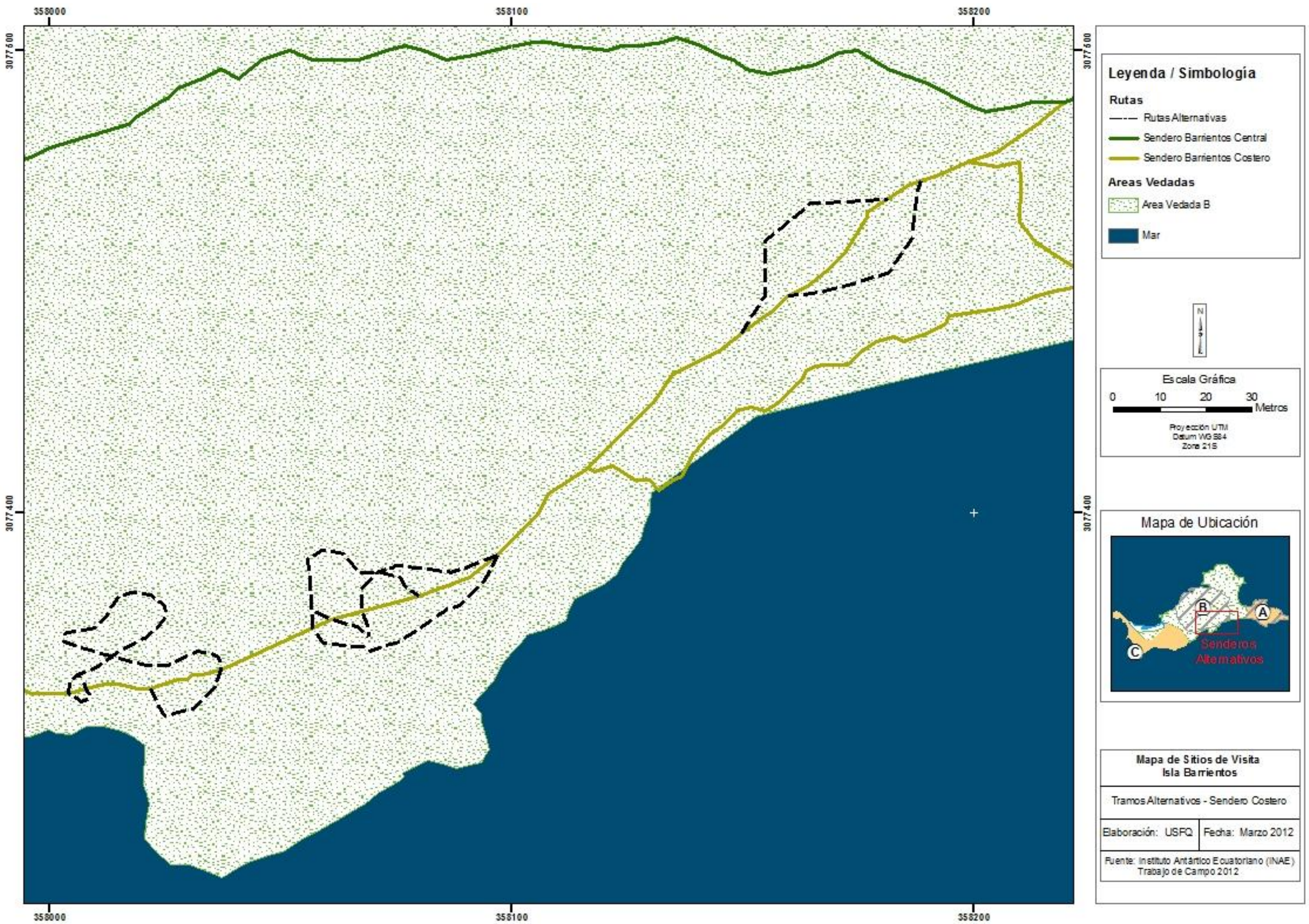


Figura 3 – Dossier fotográfico de observaciones en sendero que cruza el área vedada B

En la foto se puede apreciar como los visitantes no usan el arroyo para desplazarse y suelen impactar con sus pisadas de forma importante en la comunidad de musgos próxima.

Daños por pisoteo en una zona alejada del sendero principal del arroyo.

En esta foto también se puede comprobar como la zona de pisoteo afecta en una anchura apreciable al tapiz de musgos.

En esta imagen se puede observar como los vistantes tienden a evitar las zonas más humedas produciendose un incremento importente de la anchura del sendero.

Sendero secundario

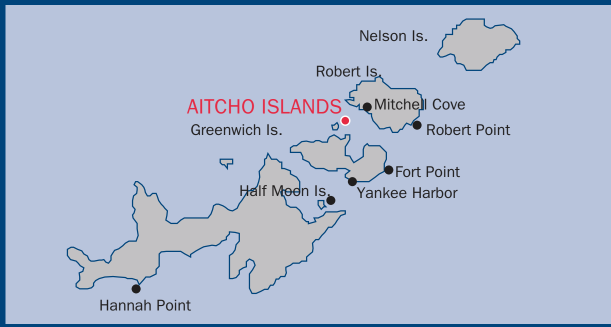
Detalle de sendero secundario donde se parecia el impacto tan significativo ocasionado a la comunidad muscinal.

ANTARCTIC TREATY
visitor site guide

Barrientos Island (Aitcho Islands)

62˚24'S, 59˚47'W

North entrance to English Strait between Robert and Greenwich Islands.



Key features

- *Gentoo and chinstrap penguins*
- *Southern elephant seals*
- *Geological features*
- *Southern giant petrels*
- *Vegetation*

Description

TOPOGRAPHY

This 1.5km island's north coast is dominated by steep cliffs, reaching a height of approximately 70 metres, with a gentle slope down to the south coast.
The eastern and western ends of the island are black sand and cobbled beaches. Columnar basalt outcrops are a notable feature of the western end.

FAUNA

Confirmed breeders: Gentoo penguin (*Pygoscelis papua*), chinstrap penguin (*Pygoscelis antarctica*), southern giant petrel (*Macronectes giganteus*), kelp gull (*Larus dominicanus*), and skuas (*Catharacta* spp.).
Suspected breeders: Blue-eyed shag (*Phalacrocorax atriceps*) and Wilson's storm-petrel (*Oceanites oceanicus*).
Regularly haul out: Weddell seals (*Leptonychotes weddellii*), southern elephant seals (*Mirounga leonina*), and from late December, Antarctic fur seals (*Arctocephalus gazella*).

FLORA

The entire centre of the island is covered by a very extensive moss carpet. Lichens *Xanthoria* spp., *Caloplaca* spp. and other crustose lichen species are present. The green alga *Prasiola crispa* is widespread.

Visitor impacts

KNOWN IMPACTS

The erosion of multiple footpaths through vegetation between the eastern and western ends of the island.

POTENTIAL IMPACTS

Further damage to the vegetation and disturbance of wildlife, particularly southern giant petrels.

Landing Requirements

SHIPS*

Ships carrying 200 or fewer passengers. One ship at a time.
Maximum 2 ships* per day (midnight to midnight).

VISITORS

No more than 100 visitors ashore at any time, exclusive of expedition guides and leaders. 1 guide per 20 visitors.
No visitors ashore between 22:00hrs and 04:00hrs (local time). This is in order to establish a resting period for the wildlife.

Visitor Area

LANDING AREA

Primary: eastern end of the island; landing either on the sand beach to the north, or on the cobbled southern beach.
Secondary: northern shore of the western end of the island, with easiest access at high water.

CLOSED AREAS

Closed Area A: Monitoring sites for chinstrap penguins above and southeast of the eastern landing area.
Closed Area B: Central part of the island covered by a very extensive moss carpet and the northern cliffs where southern giant petrels nest.
Closed Area C: Knoll on the southwestern tip of the island where southern giant petrels nest.

FREE ROAMING AREAS

Visitors can roam freely, but under supervision, anywhere except the closed areas.

Visitor code of conduct

BEHAVIOUR ASHORE

Walk slowly and carefully. Maintain a precautionary distance of 5 metres from wildlife and give animals the right-of-way. Increase this distance if any change in behaviour is observed.
When on the same level as, or higher than, nesting southern giant petrels maintain a precautionary distance of at least 50 metres. Increase this distance if any change in the birds' behaviour is observed.
Be careful near Antarctic fur seals, they may be aggressive.
Do not walk on any vegetation.

CAUTIONARY NOTES

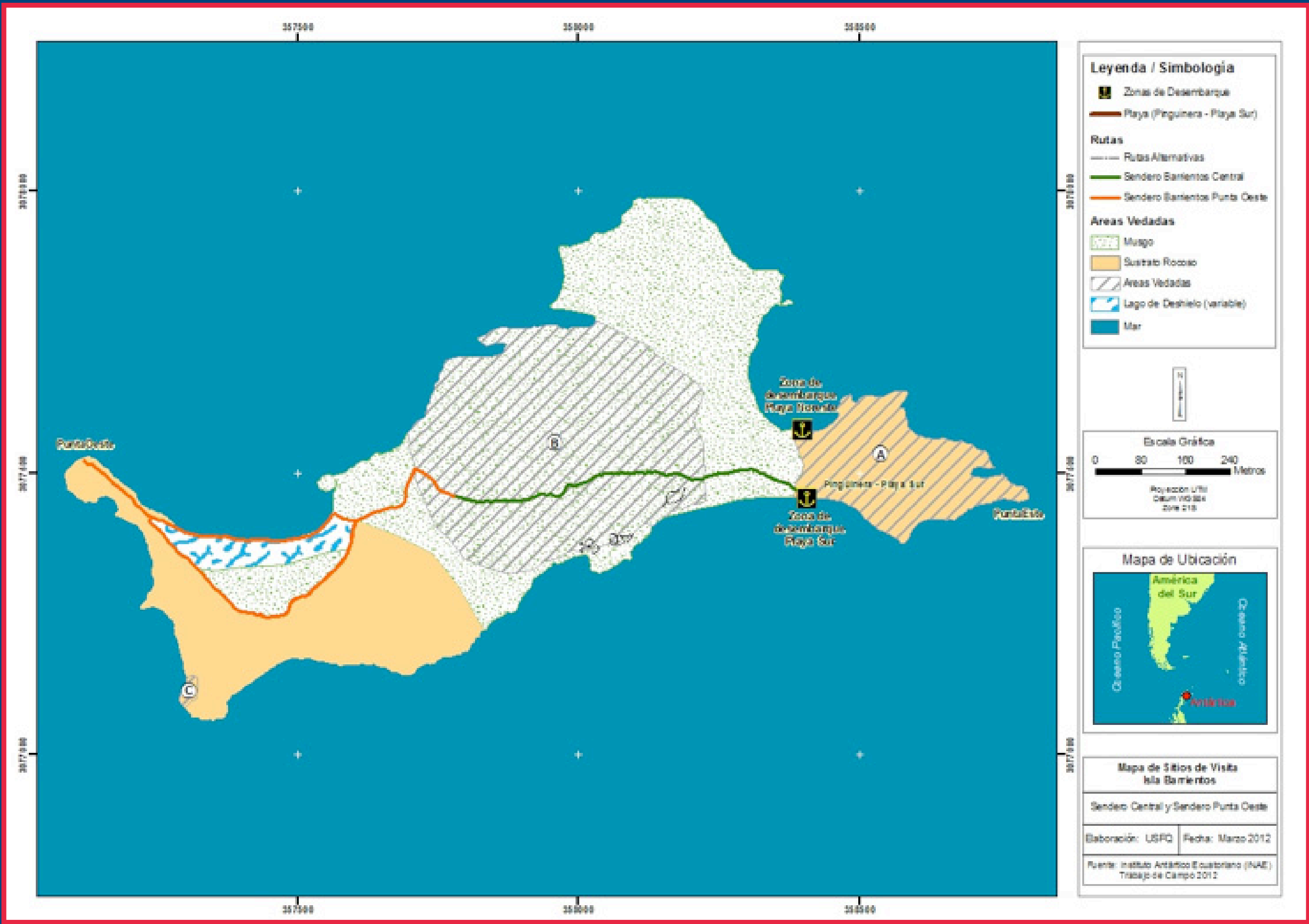
Stay clear of cliffs and vertical walls and stacks as these are prone to rock falls and slides.

* A ship is defined as a vessel which carries more than 12 passengers.

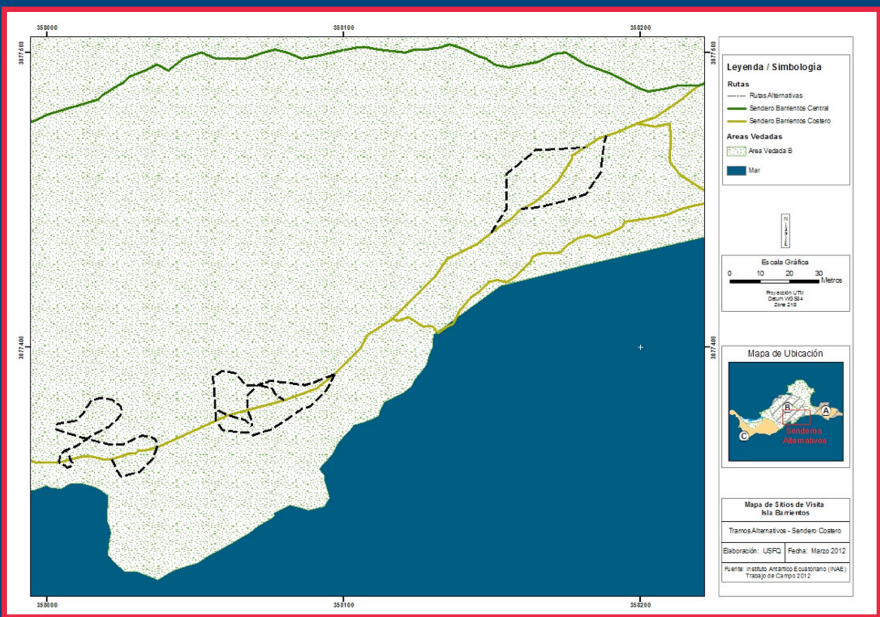
Barrientos Island (Aitcho Islands)

62˚24’S, 59˚47’W

North entrance to English Strait between Robert and Greenwich Islands.



Map of current tracks on Aitcho Islands.



Map of alternative paths formed in the path crossing the Closed Area B.

The photo shows how visitors fail to walk along the stream, and the surrounding moss community is usually significantly affected by their trampling.

IP 13

Antarctic Treaty
Consultative Meeting XXXV
HOBART 2012

Agenda Item:	CEP 8a
Presented by:	Spain, United Kingdom, Argentina
Original:	English
Submitted:	09/05/2012

Colonisation status of the non-native grass Poa pratensis at Cierva Point, Danco Coast, Antarctic Peninsula

Colonisation status of the non-native grass *Poa pratensis at* Cierva Point, Danco Coast, Antarctic Peninsula

Information Paper submitted by Spain, United Kingdom and Argentina

The grass *Poa pratensis* (also known as the smooth or common meadow-grass) was introduced inadvertently to Cierva Point, Danco Coast, Antarctic Peninsula, during transplantation experiments in 1954-55. *Nothofagus antarctica* (Antarctic beech) and *N. pumilo* (Lenga beech) trees were transplanted from Tierra de Fuego to Cierva Point to assess their capacity for survival in Antarctica. The trees did not survive; however, a grass (*Poa pratensis*) was inadvertently introduced with the trees and became established within the original experimental plot.

The previous most recent information on the colonisation status of the non-native *P. pratensis* dates back to 1995, and reported that the grass was limited to a single plant of c. 40 cm across, still situated within the original experimental plot.

During the austral summer season of 2011/12 an international research team investigated the distribution of *P. pratensis* within the area around the original transplantation site (c. 1 km^2). The survey found only a single stand of *P. pratensis* within the original experimental plot. *P. pratensis* formed a dense mat of around 1 m^2 that extended just beyond the boundary of the original plot.

The *P. pratensis* plant has extended its area of coverage since 1995 (i.e. increasing from 40 cm to over 1 m in diameter in 17 years). However, it is not known if micro-climatic conditions outside the original transplantation plot are suitable currently for further lateral growth. Neither is it known if there is potential for viable seed production, although flowers were observed during the recent survey. Nevertheless, on-going climate change in the region may enhance the likelihood of further growth and increased spatial distribution. ASPA 134 Cierva Point and offshore islands, Danco Coast, Antarctic Peninsula was designated primarily to protect the well-developed maritime vegetation and breeding colonies of at least five bird species. Spread of the non-native *P. pratensis* may put at risk the values for which the ASPA was designated.

The CEP *Non-native species manual* states that a key factor when responding to a non-native species introduction will be to assess the feasibility and desirability of an eradication attempt. Eradication of *P. pratensis* seems feasible due to the current localized extent of the plant's distribution. Given that climate change may increase the likelihood of further growth and spread of *P. pratensis,* it may be highly desirable to eradicate the plant as soon as possible.